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Localization of Auditory Spatial Targets in Sighted and Blind Subjects

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Localization of Auditory Spatial Targets in Sighted and Blind Subjects

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

by

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Abstract

LOCALIZATION OF AUDITORY SPATIAL TARGETS IN SIGHTED AND BLIND SUBJECTS

Richard W. Nuckols BS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

Virginia Commonwealth University, 2013.

Major Director: Peter Pidcoe PT DPT PhD, Associate professor, Dept. of Physical Therapy

This research was designed to investigate the fundamental nature in which blind people utilize audible cues to attend to their surroundings. Knowledge on how blind people respond to external spatial stimuli is expected to assist in development of better tools for helping people with visual disabilities navigate their environment. There was also interest in determining how blind people compare to sighted people in auditory localization tasks. The ability of sighted individuals, blindfolded individuals, and blind individuals in localizing spatial auditory targets was assessed. An acoustic display board allowed the researcher to provide multiple sound presentations to the subjects. The subjects’ responses in localization tasks were measured using a combination of kinematic head tracking and eye tracking hardware. Data was collected and analyzed to determine the ability of the groups in localizing spatial auditory targets. Significant differences were found among the three groups in spatial localization error and temporal patterns.
INTRODUCTION

Blindness refers to loss of vision, and includes a wide range of severity from full bilateral blindness to varying degrees of partial blindness. In this study, blindness was characterized as uncorrectable vision beyond 20/200, also known as legal blindness (Vorvick, 2012). There are multiple medical conditions known to cause various levels of blindness. These include macular degeneration, diabetic retinopathy, burns and accidents, stroke, glaucoma, infections, vascular issues, and birth defects/prematurity (Vorvick, 2012). According to a 2010 report by the NIH – National Eye Institute, there are over 1.2 million Americans living with full or partial blindness. This number is projected to reach over 4 million by 2050. Females make up 66% of the blind population to males 34%; and whites have the highest prevalence at 83% of the blind population, followed by blacks at 11%, Hispanics at 3%, and “other races” also at 3% (Blindness.2010).

Given the significant number of people who are blind and the challenges faced by those people in navigating their environment, the expectation is that tools would be developed to assist people who are blind. In this digital age, technology of nearly all types grows increasingly smaller, faster, and more efficient. We see these improvements maximizing communication and connections of humans to each other and to their world. One glaring exception to the current trend of technological advancement is the blind population, still often navigating with
the aide of white stick called the blind cane. The blind cane has been used globally for safety in ambulation since the 1930s, when it was introduced by James Biggs (Strong, 2009). Since then, little advancement has been accepted or adopted to improve the independence and efficacy of the blind community with navigational skills. Several electronic travel aids that have been developed include Sonicguide, the Pathsounder, the Laser Cane, and the KASPA system, although these have not become widely used in the blind community (Borenstein & Ulrich, 1997).

In order to assist in improving navigational skills, people who are blind often participate in training at state-run centers. For example, at the Virginia Rehabilitation Center for the Blind and Visually Impaired, the orientation and mobility (O&M) program offers “travel skills assessment and training, orientation technique training, and instruction in how to get around independently” (Orientation and mobility services.2012). This training includes topics such as learning spatial concepts, using a cane, and using hearing to gather information about the world. The sense of hearing becomes extremely important to people who are blind as it provides crucial information about their surroundings and is used in conjunction with other tools.

Sound is perceived via a complex sequence of auditory events that originate in the cochlea of the inner ear when tiny hair cells vibrate in response to sound waves traveling inward from the external environment (Appler & Goodrich, 2011). Vibrations from the hair cells are conducted to the central nervous system (CNS) by the spiral ganglion neurons, which have the ability to preserve multiple features of the sound waves allowing the listener to
distinguish various qualities of the sound, such as loudness, tone, and movement of the sound-source. This study was designed to capture information on subjects’ ability to localize sounds presented on an acoustic display in a closed environment as a precursor to a study that could evaluate accuracy of persons tracking actual moving targets in an open environment.

Humans are able to use auditory cues to identify and grossly locate objects in their immediate environment using audiolocation, with the most success occurring in controlled laboratory settings (Papadopoulos, Edwards, Rowan, & Allen, 2011). Ideal laboratory conditions for audiolocation tasks include sounds traveling toward the subject in a lateral fashion, little to no extraneous noise besides intended targets/sounds, and proper soundproofing or the use of acoustic boards to eliminate reverberation of sound waves. Once this skill is taken into a complex real-world environment however, the use of audiolocation for navigation or object localization becomes significantly less effective. Lateral position, orientation, and distance between the blind subject and the object generating the sound seem to be the strongest factors influencing the effective use of audiolocation in a real-world environment. Localization of sounds is achieved by the listener through a number of mechanisms. In the azimuth (or horizontal) direction, listeners can discern the object location based on interaural time differences (ITD) and interaural intensity differences (IID) based on the frequency and amplitude of the sound. For elevation (or vertical) discernment, the listener uses pinna cues that result in frequency resonances based on the position of the sound (Dobreva, O’Neill, & Paige, 2011).
Blind people are thought to have superior listening or auditory processing skills compared to sighted persons. Sensory deprivation in the form of blindness may, in fact, have a profound effect on accuracy with vocal processing and/or voice differentiation (Föcker, Best, Hölig, & Röder, 2012). During auditory location tasks in subjects with early and late onset blindness, brain imaging studies have revealed that all the subjects utilize portions of the visual cortices of the brain rather than spatial or auditory cortices (Thaler, Arnott, & Goodale, 2011). This demonstrates the neuroplasticity of the brain and an effort by these individuals to more fully utilize auditory information. O&M training has been shown to be effective in improving navigational skills as well as in improving confidence and perceived efficacy of the blind population who undergo the training (Ballemans, Zijlstra, van Rens, Schouten, & Kempen, 2012).

Based on this information, the hypothesis for this thesis was that the blind population who had undergone O&M training would be better at localizing sound compared to the sighted population. This research was also designed to investigate the fundamental nature in which people who are blind respond in localizing audible cues to attend to their surroundings. The motivation behind this research is that the information will assist in the development of better tools for helping the blind navigate their environment. The study may help determine whether there are strategies that the people who are blind use in localization of auditory targets. Successful strategies could be implemented into future training paradigms.
METHODS

In this section, a brief explanation of the experimental purpose and design is presented first. Next, a description of the equipment used in the experiment and the layout of the experimental area is given. Finally, a detailed description of the experiment and a description of the data collected are presented.

The overall experiment was designed to explore and determine the characteristics of human sound localization of spatial auditory targets in normally sighted and legally blind subjects. The experiment was comprised of three study groups and two parts. The first part was designed to characterize the relationship between visual point of gaze and head orientation during visual target localization. The second part of the study evaluated the effect of the subject’s visual capacity in localizing auditory spatial targets. The three study groups used were (1) people who are sighted, (2) people who are sighted and blindfolded, and (3) people who are legally blind.

The visually impaired subjects had all undergone Orientation and Mobility (O&M) training and currently navigated their environments using a blind cane. The average number of reported O&M training sessions for each blind subject was 3.8 with a maximum of 7 and a minimum of 1. These subjects were recruited from the Center for Blind and Visually Impaired via advertisements, through a preexisting participant list, and by word of mouth. Sighted
participants were recruited from the general population. The blindfolded/sighted group was not permitted to see the test equipment and was not familiar with the experimental area. All subjects conformed to a sample of convenience. This study was approved by VCU IRB HM14805. Subjects were required to sign a consent form prior to participating in the study and were given a questionnaire prior to collection of data. The time required of each subject to perform the experiment was between 1 and 2 hours during a single session.

In each study, subjects were seated at the end of a table and positioned such that their orientation with respect to the table was consistent. At the other end of the table was an auditory display board as shown in figure 1.

Figure 1 – World coordinate system with the subject facing the display board. The EM transmitter was positioned behind the subject.
Subjects wore a head and eye tracker and a torso tracker which were calibrated using a set protocol to define an anatomically neutral position. Subjects were orally provided with a set of instructions, including directions for the use of a hand-held directional pointer, and were given a pushbutton as a means of signaling target identification and the end of each experimental trial. As applicable to the specific test, subjects were asked to perform the task of localizing spatial targets using their visual and/or auditory senses, depending on which of the part of the experiment being performed. Details for each will be described later. Subjects’ localization ability was measured by their ability to fixate their eye gaze within the plane of the targets, direct their head, and direct the directional pointer at the suspected location of the target. The response data was recorded using motion tracking and eye gaze tracking equipment.

The key equipment used to perform the experiments is described below:

**Motion Tracking Equipment**

Kinematic motion data were measured and recorded using The Motion Monitor™, Innovative Sports Training Inc. This system uses electromagnetic tracking technology from Ascension Technology. The system consists of an electromagnetic (EM) field generator, coil sensors, and software. Based on the strength of the EM field on the 3 coils within each sensor, six degrees of freedom (DOF) data pertaining to sensor location and orientation was collected at a sampling rate of 100 Hz. The advantage of using an EM type motion tracking system was that motion can be captured using a small number of sensors. The reported accuracy of the system is 1.8mm RMS in translation and 0.5° RMS in rotation with a reported resolution is 0.5
mm and 0.1° respectively. Technical details for this system are provided in Appendix 1. The disadvantages of an EM-based system included the limited range of the EM transmitter, interference due to metallic objects in the measurement space, and a nonlinear system response. To minimize the error associated with the EM system, the subject was seated near the transmitter, and any metal surrounding the EM generator and the study area was minimized. In addition, a distortion map of the study area was used to linearize any remaining errors across the measurement space. This process reduced measurement errors to less than 20mm. To further ensure limited distortion within the study area, a verification test was performed. This process involved attaching two sensors to opposite ends of a 12 inch long rigid rod and moving the rod slowly within the study space while collecting continuous data. In a space with limited distortion, the change in distance between the sensors would be minimal. When this test was performed in the study space, the average error was 2mm±8. The maximum absolute error during the sweep was 40mm. The maximum error might have been larger than the error defined in the world coordinate process due to the expanded area covered during the sweep. Equipment such as the sound chamber was also added and could have slightly distorted the calibrated map.

The four EM sensors used in all experiments were placed on (1) a hand-held stylus, (2) attached to the subject’s head via the helmet housing the eye tracking system, (3) attached to the torso, and (4) attached to a hand-held directional pointer. The stylus was calibrated so that the stylus tip position was known in relation to a sensor bound to the stylus with typical RMS errors around .001 meters. Using the stylus, a world coordinate system was defined in the
study space to establish a right hand coordinate system with units in meters. The world coordinate system was defined as shown in Figure 2.

![Display Board](image)

**Figure 2 – World coordinate system with the subject facing the display board.**

The origin of the world coordinate system (0, 0, 0) was in the right corner of the display table. The subject faced the positive y direction, the positive x axis directed to the left of the subject, and the positive z axis was directed towards the floor.

Sensors two and three were attached to the subject’s head and torso respectively, as shown in Figure 3. During the subject setup at the beginning of each data collection additional subject landmarks were digitized to orient the head and torso into the data collection environment. These landmarks included the spinous processes of C7 and T12, and the occipital protuberance of the head. Digitization was performed with the subject seated in an
anatomically neutral (predefined) position. From these data, in addition to trunk-in-space and head-in-space data, relative orthopedic angles between the head and trunk could be calculated.

Figure 3 – Sensor 2 (Head) and Sensor 3 (Torso) placed on a subject.

The fourth sensor was placed on a hand-held directional pointer that the subject was instructed to control with his dominant hand. Two landmarks along the longitudinal axis of the pointer were digitized to define the pointing vector. The hand-held pointer is shown in figure 4 and remained on the table surface for all experiments.
At the completion of the calibration process, the motion tracking sensors were oriented with the body parts of interest and kinematic metrics could be collected and recorded.

**Eye Tracking Equipment**

An EyeLink II™ system (SR Research Ltd) was used to measure and record binocular horizontal and vertical eye position in sighted subject experiments. It had a sampling rate of 250 Hz. When used in conjunction with the Motion Monitor equipment, eye-in-head data was linked to head position to provide binocular gaze. For analysis, data from this combined system was exported at the 250 Hz rate. To ensure data integrity, the Motion Monitor (100 Hz) data was linearly interpolated and synchronized to the EyeLink II data via an internally generated timestamp.

The EyeLink II system was calibrated per the instructions in the user guide. The cameras were aligned below the visual line of sight to capture pupil size and corneal reflection. The reported accuracy and resolution of the system is <0.5° and 0.025° RMS. Additional details are provided in Appendix 2. A typical setup screen from the EyeLink II is shown in Figure 5.
illustrating the image size and quality. The calibration board is shown in Figure 6. It was positioned 1.13 meters away from the world coordinate system origin along the positive y-axis, centered, and in the xz-plane. The calibration process was automated. Once initiated, the subject was asked to fixate on sequentially lighted LED targets. A 1000ms gaze fixation triggered target advancement.

Figure 5 – Eye Link II system screen following setup of the cameras.

Figure 6 – Calibration board for the EyeLink II system.
The EyeLink II system was calibrated to encompass a visual angle of 28° in the azimuth and 27° in the elevation. The reported gaze tracking range of the EyeLink II system is 40° in the azimuth and 36° in the elevation, so the range of calibration was well within the specifications of the device. The addition of the motion tracking equipment to the EyeLink system enabled the subjects to move freely during data collection. The calibration space encompassed approximately 50% of the acoustic display in the azimuth and 85% in the elevation. A sample showing the accuracy of the EyeLink II system within the calibrated space is shown in Figure 7. The average error in localization of the 9 LED targets was 0.39° in azimuth and 0.43° in elevation with a standard error of 0.027° and 0.03° respectively.

![Figure 7 – Eye gaze tracking on calibration targets](image)
Sound Display Equipment

Because the experiment focused on analyzing the subjects’ ability to localize spatial auditory targets, a means of presenting sounds to the subject was required. The goal was to deliver sounds to the subject from various spatial positions in both the azimuth and elevation as well as create a display that is capable of presenting a moving sound source. The sound board was located 1.13 meters away from the world coordinate system origin along the positive y-axis, centered, and in the xz-plane (in a location similar to the calibration board.) To display the sound, the display board used a series of stationary speakers that could be individually activated. A similar approach has been used in other studies to present distinct sound sources in space as well as simulate motion (S. Getzmann, 2005). Although the speakers were not physically moving, the appearance of motion could be presented in what is termed virtual motion. Not only could individual sounds be presented in the study space and moving sounds simulated, but multiple overlapping sounds could also be presented at the same time and in various locations throughout the study space. This approach provides versatility in target presentation.

Piezo speakers were selected to deliver the sound to the user. These speakers are small, inexpensive, and can easily be placed in a grid to create the sound display. They also generate less EM noise than traditional magnetic coil speakers and therefore theoretically produced minimal interference with the data collection equipment. The piezo speaker selected for the experiment is the APS308S-R (Pui Audio). The bandwidth for the speaker is 300-20,000 Hz (similar to normal human hearing), with resonance at 800 Hz and a minimum output sound
pressure level (SPL) of 80 dBA. The piezo speaker measured 18x26x1.8mm in size. More information on the piezo speaker can be found in Appendix 3.

Based on the selection of piezo speaker and presentation requirements, a display board was fabricated from plywood using a computerized numerical control (CNC) machine so that the speakers could be placed in a precise grid pattern. The piezo speakers were spaced 3.45 cm on center in both azimuth and elevation. This provided an angular resolution of 2° between speakers when presented to a subject seated at a distance of 1 meter from the sound board. Previous studies have shown that the accuracy of people in localizing sounds is within 5° (Shelton & Searle, 1980), and previous studies using virtual motion with piezo speakers found that placing the speakers within the 5° spacing allowed for seemingly continuous transition of the sound (S. Getzmann, 2005). The sound display contained a total of 305 speakers oriented in 17 columns and 17 rows. In addition, the middle row was extended to the full length of the display, and speakers were placed at the outer corners. In this experiment on static target localization, every other row and column was used and resulted in a display of 15 columns and 9 rows. Display column numbering began at the right of the display board with column 1 and progressed to the left. The display row numbering began at the top of the board with row 1 and progressed down. This arrangement resulted in 91 piezo speakers being used for this experiment. The additional unused speakers were intended for use in generation of virtual motion and required smaller angular resolution between speakers. The final display showing the speakers is shown in Figure 8.
Figure 8 – Piezo speakers on sound display board. Every other row and column was used in this experiment resulting in 15 display columns and 9 display rows.

The majority of the speakers were placed in the central region of the board, representing a focus area for the subjects. Four speakers were placed at the corners of the sound board and were used to acoustically define the outer perimeter of the display. Speakers were attached to the board using hot glue. Finally, the board was covered with black fabric to prevent the sighted subjects from focusing on individual targets during the acoustic localization experiments that follow.

Due to the flat panel design of the display, the speakers along the periphery were further away from the listener, and were not directed directly at the subject. This distance was not perceived as a problem due to the minimal change in distance and the lack of echoes within the chamber. The calculated sound level decrease due to the increased distance was 0.74 dB based on the inverse distance law for sound pressure ($p \alpha \frac{1}{r}$) and is considered minimal.
Control of Speakers:

Each of the 91 speakers within the grid required independent control. The activation of each speaker was controlled through a solid state relay, a DIO card, and LabView software. Figure 9 shows the schematic for the speaker control. Figure 10 shows the physical layout of the wiring.

![Schematic for speaker control](image)

Figure 9 – Schematic for speaker control. Note that each speaker could be controlled independently and that a common sound source was presented to each speaker.

Figure 10 – Physical layout of the wiring.
Figure 10 – Physical layout of wiring as viewed from the back side of the sound display board.

A grid pattern was used to provide the repetitive wiring of the sounds source inputs and the ground return for the relays.

**Solid State Relays**

A solid state relay was selected to enable/disable each speaker because it provided fast switching and does not exhibit the audible popping noise characteristic of mechanical relays. Due to the low current requirement of the piezo speaker, the solid state relay was a viable choice. The relay used in the experiment is the TLP222G TOSHIBA photocoupler with an average switching time of 0.3ms (on) and 0.1ms (off). Because the subject response time was not considered an experimental variable in the experiment, the switching time was not a concern. Additional specifications are provided in Appendix 4. A relay was required for each of the speakers; therefore, a total of 91 relays were used. The four leads of a single relay are shown in Figure 11. The control side of the relay was connected to one of the digital outputs of the DIO card. The signal from the audio amplifier was wired to pin 3 on the load side of the relay and pin 4 was wired to the piezo speaker.
The NI6509 100 pin DIO card was used in the experiment to control the solid state relays. The DIO card allows for independent control of the 5V outputs. Multiple outputs can be used simultaneously and an external power source can be used if more power is required. The DIO card is shown in Figure 12. The DIO card attached to the sound display and is shown with wires connected in Figure 13. Additional specifications as well as the wiring configuration are provided in Appendix 5.
LabView Code

LabView code was written to control the output of the DIO card. Two programs were used in the experiments. The first program was used to control the outer corner speakers so that they could be used to acoustically define the display space. This portion of the experiment was termed the acclimation phase. In the acclimation phase, sound from the four perimeter corners of the display board were presented to the user sequentially in a clockwise fashion starting with the top left corner. The speakers were automatically progressed after a period of three seconds for each speaker. Further details on the acclimation phase are given in the experimental details section later in this document.

The second program was used in the main section of each experiment and was used to display to the subject the series of 91 randomly ordered single auditory targets with no target repeats. An array containing the target numbers from zero to 90 was randomized within Excel and stored as a text file. This 91 line text file was loaded in LabView as the “selection array”.

Figure 12 – DIO card; Figure 13 – DIO card attached to sound display
The value of each element within the selection array corresponded to an index in the DIO card array which corresponded to the individual speakers. Sequentially, the randomized elements within the selection array were chosen. The corresponding DIO card index was turned on, the corresponding relay contact was closed, and the speaker was turned on. For example, the first element of the selection array was 56. Once the DIO card array was cleared, the value for index 56 was set to 1. The DIO card provided 5V to relay 56, the contact closed, and the speaker was turned on. A digital input from a subject-controlled push button was used to control the sequential progression of the auditory cues. This button also demarcated target acquisition and event-marked the kinematic metrics. A NI DAQ 6009 card and rising edge detection within the software was used to detect the push button signal. Upon detecting the push button signal, a delay of 3 seconds was given before the next sequential auditory cue delivered. The LabView code can be found in Appendix 6. A different target randomization order was presented to each subject.

**Sound Source**

A common sound signal was wired to the load side of each of the relay contacts. When the desired relay was energized, the contact of the selected relay closed, and the signal passed to the piezo speaker. This design ensured that the sound signal delivered to each speaker was the same.

The sound signal chosen for the display was pink noise. This broad spectrum noise provided the high frequency/pinna cues that were needed in elevation determination and also provided satisfactory lower frequency interaural time differences cues for azimuth.
determination. Generally, pink noise is thought to be less irritating to the participant than white noise when presented for long periods of time although there is no empirical evidence available to support this theory. The energy of pink noise drops off at 3dB per octave with a power spectral density of $S(f) \propto \frac{1}{f}$. Therefore the low frequency noises are more prominent. The source of pink noise was the CD “Digital Pink Noise” by Luxe Vivant and was played through a computer.

The sound output from the computer line out was delivered to the input of an amplifier (Panasonic SA-HT80). The impedance of the amplifier designed for magnetic 4Ω speakers was not configured for the high voltage and low current characteristic of the piezo speaker. Therefore, a 4Ω resistor was placed in parallel with the piezo speaker to help match the impedance of the amplifier. One leg of the amplified signal was wired to the contact on the relay. The second leg was wired to the negative side of the piezo speaker and completed the circuit when the relay was energized. The volume was preset prior to the experiments and was easily heard by subjects with normal hearing.

**Sound Chamber**

A sound chamber was constructed to reduce the external noises and limit the possibility of echoes from the sound targets. A picture of the sound chamber is shown in Figure 14. The frame of the structure was built with 2x4s. The internal sound insulation was 1” pyramidal sound foam that reduced echoes and limited external noise. The external insulation was 3/4” extruded polystyrene insulation board.
Figure 14 – Testing sound chamber. The chamber measured approximately 12’x5’x8’ and was enclosed on 5 sides. The subject was seated at the open end facing inward.

Description of Experiments and Subject Testing

The experiment was designed to explore and determine the characteristics of human sound localization of spatial auditory targets in three study groups. The experimental design was a combination of a between-group and a within-subject design. The between condition had three levels: sighted, blindfolded, and blind. The within-subject conditions were trial (1 and 2), display column (15 columns), and display rows (9 rows). A diagram providing an overview of the experimental design is provided in Figure 15.
Part 1 was performed on normally sighted subjects (Group 1) and evaluated the subject’s ability to orient their head to a defined target. These data characterized the relationship between visual point-of-gaze, a high accuracy standard, and head orientation during visual target localization in normally sighted subjects. Part 2 evaluated the effect of the subject’s visual capacity in localizing auditory spatial targets. This part was performed on normally sighted subjects (Group 1), blindfolded subjects (Group 2) and the subjects that were blind (Group 3).

The first group, Group 1, was sighted, permitted to use vision, had no uncorrectable visual deficits, and had no reported hearing deficits. This group was required to wear contact
lenses if vision correction was required. The second group, Group 2, was sighted, blindfolded, and had no uncorrectable visual deficits and no reported hearing deficits. This group was not permitted to see the experimental setup and had no knowledge regarding the space. The first and second sighted groups had no experience with O&M training. The third group, Group 3, was comprised of people who were required to be legally blind and had no reported hearing deficits. In addition, they all had to have received O&M training. The subjects in the group were all capable of ambulation using a white cane to navigate their environment. This sample was considered to be a typical representation of independent people who are blind. There was no requirement on the subject being congenitally blind or adventitiously blind. All blind subjects were made to wear a blindfold to rule out the impact of partial sight. The studies were approved and performed under VCU IRB number HM14805.

The participants in Group 3 were recruited from the Center for Blind and Visually Impaired, through a preexisting participant list, and by word of mouth. Due to the specialty and limited number of blind participants, these participants were paid $10/hour for their participation. The sighted participants were recruited from the general population, and the blindfolded/sighted group was distinct from the non-blindfolded/sighted group. The blindfolded/sighted group was not permitted to see the equipment and was not familiar with the experimental area. The sighted subjects were not paid for their participation. All subjects were prescreened to ensure that they fit the inclusion criteria of these experiments.

A total of 16 participants were recruited for the study with 5 blind subjects, 5 sighted subjects, and 6 subjects that were sighted and blindfolded. The average age of the subjects
was 53 years for the blind population and 39 years for the blindfolded and 30 for the sighted. Despite the age discrepancy, neither group reported any age related hearing loss. The male/female ratio for recruited subjects was 0.5. A summary of the participant demographics is given in Appendix 7.

The within-subject factors are further described in the experimental protocol. The trial, display row, and display column were treated as repeated measures.

**Experimental Protocol**

The consent form was provided to the subjects and questions were answered prior to performing the experiment. The legally blind subjects consented orally. Following the signing of the consent form, a questionnaire was provided. The questionnaire determined the participant’s level of vision, hearing, and any previous participation in O&M training. Each subject was assigned a participant number and all collected data was de-identified and stored in a secure location.

**Part 1**

The first study was performed on normally sighted subjects (Group 1) and was designed to characterize the relationship between visual point-of-gaze and head orientation during visual target localization. Data from part 1 of study one was used to assess whether subjects were capable of directing their heads at an intended location. The subjects were instructed to focus their eye gaze, head direction, and the hand-held pointer at the specified visual targets.
Subjects were first introduced to their experimental surroundings. Subjects were seated at the end of an acoustic bench and positioned such that their orientation with respect to the bench was consistent. The subjects’ feet were placed to the inside of the table legs to keep them orientated towards the display. A description of the display area was orally provided to the subjects as defined in the protocol. Subject sensors were then placed on the participants. With the subjects sitting in an anatomically neutral position, the sensors were configured and additional landmarks were digitized using the calibrated stylus. Additional landmarks were digitized to define the head gaze vector and the pointer vector.

The EyeLink II system was calibrated and validated using a 9-point target matrix. After this, an additional verification step was undertaken to ensure the accuracy of the EyeLink II system. The participants were told to fixate their gaze on an inner series of nine visual targets and eye gaze data was collected. The eye gaze intersection points were quickly analyzed to ensure that the calibration was acceptable. The data was analyzed visually in Excel similar to what is seen in figure 6 to ensure that the gaze vector intercepts intersected the target locations.

With the equipment setup complete, instructions were provided to the subjects to focus their eye gaze, head orientation vector, and handheld pointer at the specified visual target. The handheld pointer was kept on the surface of the table. The nine visual targets represented in this section were the same as the targets used in calibration. Data were collected in an activity file that reflected the subject’s response to each of the visual targets.

Part 2
The second study investigated the effect of vision on the subject’s ability to accurately localize spatial auditory targets. Subjects used in this study were from Group 1, Group 2, and Group 3. The goal of the study was to compare the difference in auditory localization ability among the normally sighted group, blindfolded normally sighted group, and blind group. Although the display board was covered during Study 1 and individual speakers were not visible, the sighted subjects were still able to visually identify the boundaries of the display space. The hypothesis of this study was that visual cues provide an advantage in localizing spatial targets in a defined space.

The sighted group continued immediately into part 2 of the experiment following the completion of the visual tasks. Because the tasks in the two parts used different modalities for target identification, visual vs auditory localization, it was not believed that there was any training effect. Except for Group 1 performing the visual task in part 1, the protocol for performing in auditory localization is identical among the three groups.

The subjects were first introduced to their experimental surroundings. Subjects were seated at the end of the acoustic bench and positioned such that their orientation with respect to the bench was consistent. The subjects’ feet were placed to the inside of the table legs to keep them orientated towards the display. A description of the display area was orally provided to the subjects as defined in the protocol. The subjects’ donned the sensors and were calibrated in an anatomically neutral position. Additional landmarks were digitized to define the head gaze vector and the handheld pointer vector.
Subjects were given specific instructions on the way to focus their head orientation vector and the pointer at the specified auditory target. For directing their head, subjects were told to imagine a focused beam or pointer extending directly from the bridge of their nose outwards and were instructed to direct the beam at the sound source. For the pointer, they were instructed to hold the pointer in your dominant hand and direct the tip of the pointer at the sound source while keeping the pointer on the table. Once directed at the location of the sound source, the subjects were instructed to hold the positions when pushing the button.

Prior to performing any auditory localization tasks, the acclimation phase was presented to the subjects as a way of outlining the boundaries of the acoustic space and making the subjects familiar with the auditory study space. The sounds from the four outer corners were presented to the subjects in clockwise pattern with three repetitions. At the end of the acclimation phase, the subjects were told to direct their head and pointer at the center of the space.

Next, in the localization phase of the acoustic study, the 91 spatially distributed auditory targets were presented to the subjects in random order. Subjects were directed to localize the sound and focus their eye gaze (if applicable), head orientation and the pointer in the direction of the sound source. Subjects were instructed to push a button while focusing on the suspected sound location. After a brief delay of 3 seconds, the next sound location was presented to the subjects. The 91 independent sound sources were sequentially presented to the subjects and data was collected based on the subjects’ response to each of the auditory targets. An activity file was saved in the Motion Monitor system for each sound target.
Recording of the subjects’ physical response began when each sound was presented and ended one second following the button push.

Following the localization phase, the acclimation phase was again presented to the subjects and they were directed to realign to the center of the display area. After a brief break, a second identical trial was performed, providing two sets of data per subject.

Data Collection and Processing

As described in the experimental protocol section, individual activity data files were stored for each visual localization activity, and for each localization task of the individual auditory sound targets. This data from the experiments was exported from the Motion Monitor system for analysis in MATLAB. The Motion Monitor sensor data was recorded at a sampling rate of 100 Hz. When the EyeLink II system, sampling rate of 250 Hz, was used, the Motion Monitor system data was linearly interpolated by the Motion Monitor software when the data was exported. This was justified based on the low frequency of body kinematics. The data was also synchronized based on a timestamp from the EyeLink II system. Interpolation of the kinematic data was accounted for in the data processing where one script was defined for the sampling rate of the sighted subjects (250Hz) and another for the subjects that were blindfolded and blind (100Hz).

The data collected for each subject was substantial. Depending on the group, data collected for each subject included up to 36 visual localization observation files, and 182 auditory localization files. The data analysis performed depended on the experiment and the group. Data was imported and processed in MATLAB. The code is provided in Appendix 9.
Determination of subject head orientation and targeting accuracy

A crucial requirement of the experiment was the ability to determine the accuracy of the subject in localizing spatial targets. To accomplish this task, three vectors were defined and the positions of the spatial targets were measured. Eye gaze vector could not be used in the experiment for blind and blindfolded subjects. Therefore, the head direction vector was developed to allow the researcher to determine the location to which the subjects were attending. A directional pointer had been used in previous experiments and was also used in this one (S. Getzmann, 2005).

The three vectors defined for the experiment were the eye gaze vector, head direction vector, and the handheld pointer vector. The eye gaze vector was determined from a combination of data from the EyeLink system and Motion Monitor system. The eye gaze vector (or eye-in-head data) was defined as the normal vector originating at the location between the right and left eyes. The normal vector is the normalized average of the right and left gaze vector, and the origin location is the average of the right and left eye pupil location. The eye gaze vector accurately portrays the gaze vector in both azimuth and elevation. This eye gaze vector data was anchored to the head-in-space data supplied by the Motion Monitor system. The combination provides eye-in-space data and attaches the eye position (or gaze vector) to the world coordinate system.

The head direction vector (HDV) was defined by a normal vector originating at a calculated center of rotation within a subject’s head and passing through the bridge of the
nose. The vector is shown in Figure 16.

Figure 16 – Position of sound board and in relation to the subjects head direction vector (HDV). An example of azimuth and elevation errors is also shown and is based on a HDV that does not match the target on the display board. These errors are measured in degrees.

The center of rotation for the head was calculated as follows. An initial estimate was made for the head vector using the bridge of the nose and the occipital protuberance as anatomic markers. The midpoint of this vector was determined. An additional vector that extended from the bridge of the subjects nose to the actual location of the auditory targets, heard during the localization experiments, was calculated. A correction vector was then applied to the center of rotation point based on the subjects’ average responses to the centerline auditory targets during the localization experiments. The correction was required
due to the inaccuracy of defining the head vector based on the occipital protuberance and bridge of the nose. Data for the correction vector was taken from the data collected during the subject auditory trials. For the correction in the azimuth direction, the centerline column of the display (column 8), corresponding to \( x = 37 \) cm, was used and an average correction vector component in the \( x \) direction was calculated. For the correction in the elevation direction, the centerline row of the display (row 5), corresponding to \( z = -14.75 \), was used and an average correction vector component in the \( z \) direction was calculated. The \( y \) component of the correction vector was taken as an average of the centerline corrections. This correction vector was applied to the location initially calculated as the center of the head to generate a corrected center of rotation point within the head. The data from the localization experiments was reanalyzed using the correction vector to redefine the center of rotation point. The head direction vector (HDV) used for analyzing head orientation has been corrected using this method.

The third vector was the hand held directional pointer vector (DPV) from the stylus in the subject’s dominant hand. During the sensor setup process, two defined locations on the pointer were digitized. Subjects were told to leave the pointer on the table and rotate/slide the pointer to the direction of the suspected target. The pointer vector was defined as the normal vector extending from the tip of the pointer. Because the pointer remained on the table, the pointer only provided information regarding azimuth orientation.

The location of the auditory targets was measured with respect to the world coordinate system origin. In accordance with the defined world axis, the \( x \) axis increased from the right to
left and the z axis increased from top to bottom. The y axis, depth direction, was held constant at a distance of 1.136 meters from the origin that represented the position of the targets. The position of the targets is described in Appendix 8.

**Spatial Error Terms**

The data from Group 1 for visual localization of targets included the eye gaze vector, head orientation vector, and eye in head angles. The button push was used as the marker for when the subject was focused on the suspected target location. The eye gaze azimuth and elevation angles were determined at the time of button push. The EyeLink II system contained flags in the exported data that indicated the presence of eye saccades or a fixed gaze. Observations where the gaze was not fixed were removed by visual inspection.

The metric used to assess the localization of auditory targets was the head orientation vector. The button push was used as the marker for when the subject was focused on the suspected target location. Data was extracted from the 0.5 second prior to and following the button push for a total of one second of data. Within the one second of data, a 10-point moving average was performed to determine the time of minimal head vector error. The data was also checked for quality using an algorithm that calculated a standard deviation in the head angular error within the time period. Observations where the standard deviation in the angular azimuth and elevation error exceeded 0.25° were removed.

The ability of the participant to localize the spatial targets was determined by three error terms. Spatial error terms were defined based on the subjects’ head orientation vectors
and the known position of the targets in the space. The error was classified as either an angular error measured in degrees or a distance error measured in centimeters.

The angular error was defined as the angular difference between the corrected center of rotation to target vector (HTV) and the corrected head direction vector (HDV). The angular error terms were split between the azimuth angle and the elevation angle as shown in figure 16. The azimuth error was the angle error of the head direction vector in the azimuth (x direction). The elevation error term was the angle error of the head direction angle in the elevation direction (z direction). The angular error terms were further subdivided into relative error and absolute error. The radial error term was the absolute error as determined by the difference between the gaze vector intercept position and the actual target position.

Absolute error did not take into consideration the sign of the error. This term gave an indication of the subjects’ overall error. Relative error took into consideration whether the HDV was to the left/right or above/below the target. The sign convention used for the angular error is positive for error to the right/above the target. The radial distance error terms calculated based on the distance between the auditory target location and the location in which the HDV pierces the display board. Error terms were further subdivided into relative error and absolute error. The sign convention used for the error terms is positive for error to the right/above the target.

Temporal Analysis

The subject’s response in localizing the auditory targets was assessed based on the observed head sweep strategy, and the time taken to complete the trials. The head sweep
strategy metrics were based on the path length of the head angle during each trial and the number of velocity transitions. Similar to the spatial analysis, the angular path length and transition data were broken into azimuth and elevation components. The transitions were calculated from the local extremes in the temporal-spatial data and represented changes in direction. The data was smoothed using a 10-point moving average, and a minimum change in head angle (2°) was required to indicate a local extreme. This method minimized noise, but retained important transitional information. The time data was recorded from the beginning of each trial to the time of button push and was analyzed to determine the time for localization of the targets. A temporal analysis was also performed in the localization data to rule out drift in the subjects’ responses. A run sequence plot was performed for each subject and the residuals were plotted against the run order.

**Statistical Considerations**

**Spatial Error Terms**

- Absolute Error: The absolute error data was analyzed using the Generalized Estimating Equation (GEE) with a gamma distribution and log link. The absolute error data had an exponential decay shape, and the homogeneity of variance condition was not satisfied, so traditional parametric analysis was not possible. The GEE also allows for many distributions, does not require homogeneity of variance, and allows for repeated measure analysis.
• Variability of Error: The standard deviation of the relative errors for the groups was calculated independently for each group. The test for homogeneity of variance was calculated for the relative error terms and reported as the Levene Statistic.

• Relative Error: The relative error data was analyzed using the Generalized Estimating Equation (GEE) with a gamma distribution and log link. The relative error data did not satisfy the normally distributed criteria, and the homogeneity of variance condition was not satisfied, so traditional parametric analysis was not possible.

Temporal Error Terms

• Path Length: The path length data was analyzed using the Generalized Estimating Equation (GEE) with a gamma distribution and log link. The data had an exponential decay shape, and the homogeneity of variance condition was not satisfied, so traditional parametric analysis was not possible.

• Transitions: The number of transitions was analyzed using the Generalized Estimating Equation (GEE) with a Poisson distribution and log link. This distribution is typically used for counting events in a given time. The data had an exponential decay shape, so traditional parametric analysis was not possible.

• Time: The time for localization was analyzed using the Generalized Estimating Equation (GEE) with a gamma distribution.

• Drift: A run sequence plot was used to assess the drift in the subject’s orientation. A linear regression line was fit to the residuals and a drift in orientation was calculated over the 91 trials for each subject.
Results

Visual Localization

The first part of the experiment was designed to characterize the relationship between visual point-of-gaze and head orientation during acoustic target localization in normally sighted subjects. The data from the experiment shows that there is a correlation between the location to which the participants were directing their eye gaze, and the direction they were aiming their head direction vector. The data from the participants in visual target localization is shown in figure 17. The mean relative difference between the subjects point-of-gaze and head orientation was found to be 0.026°±.14 in the azimuth and 0.731°±.17 in elevation. Data of the eye in head were also examined to assess the participants’ ability to direct their eye gaze and head direction vector to the same location. Following visual target identification, data from the participants shows that the subject’s eye angle returned to near zero. Because the subject was holding point-of-gaze on the target, these data suggest that the subject was turning their head to align with the point-of-gaze. Typical eye gaze angle data is shown in figure 18.
Figure 17 – Relationship between point-of-gaze and head orientation during visual localization of targets.

Figure 18 – Typical eye gaze angle data during identification of visual targets. The eye angle returns to near zero indicating that the head is realigning with eye in localization of target.
Auditory Localization

Absolute Angle Error in Azimuth

The marginal mean azimuth error for each group is shown in figure 19. The distribution of the error for the absolute azimuth error for all three groups is shown in figure 20. The data is not normally distributed so a generalized linear model is used where a gamma distribution with a log link was defined.

![Figure 19](image_url)

Figure 19 – Marginal mean azimuth error for the three groups. A significant difference is observed among the three groups.

![Figure 20](image_url)

Figure 20 – Histogram showing the distribution of absolute azimuth error for all groups
Test show that the group (p = 0.000) and column (p = 0.000) are main effects. There is also an interaction effects of row*column (p = 0.000) and group*row (p = 0.000). Table 1 summarizes the data of the GLM analysis. The analysis also indicates significant marginal mean differences in a pairwise comparison between all the groups that is summarized in Table 2. Independent analysis by GLM between the groups shows that a significant effect of group is observed between Groups 1 and 2, 2 and 3, and 1 and 3.

Table 1 – Summary of GLM data analysis in absolute azimuth error

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<tr>
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<th>Sig.</th>
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Table 2 – Pairwise comparison of group in absolute azimuth error

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Contrast analysis of the data shows significant shapes of error in the azimuth and elevation direction. The contrast analysis shows a quadratic contrast for the azimuth marginal...
mean error with the elevation position variable although the contrast is not significant. The contrast analysis shows a significant 4\textsuperscript{th} order contrast for the azimuth marginal mean error with the azimuth position variable. A typical plot of the azimuth error marginal means for the display column effect and display row effect is shown in figure 21.

![Typical marginal mean azimuth errors relative to the elevation direction and the azimuth direction.](image)

Figure 21 –Typical marginal mean azimuth errors relative to the elevation direction and the azimuth direction.

**Absolute Angle Error in Elevation**

The marginal mean elevation angle error for each group is shown in figure 22. The distribution of the error for the absolute elevation error for all three groups is shown in figure 23. The data is not normally distributed so a generalized linear model is used where a gamma distribution with a log link is defined.
Figure 22 – Marginal mean elevation error for the three groups. The blind group is statistically different from the sighted and blindfolded groups. There is no statistically significant difference between the sighted and blindfolded groups.

Figure 23 – Histogram showing the distribution of absolute elevation error for all groups

The test shows that the group (p = 0.01), row (p = 0.000), column (p = 0.000) are all main effects. There are also interaction effects of row*column (p = 0.000 and group*row (p = 0.000). Table 3 summarizes the results of the GLM analysis. The analysis indicates a significant marginal mean difference in a pairwise comparison between Groups 1 and 3 and between Groups 2 and 3. The data is summarized in table 4. Further analysis of Groups 1 and 3 indicates
that there is a significant effect of the group. Likewise, an analysis between Groups 2 and 3 indicates that group is a main effect.

Table 3 – Summary of GLM data analysis in absolute elevation error

<table>
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<tr>
<th>Source</th>
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Table 4 – Pairwise comparison of group in absolute elevation error

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Contrast analysis of the data shows significant shapes of error in the elevation and azimuth direction. The contrast analysis shows a significant quadratic contrast for the elevation marginal mean error with the elevation direction. The contrast analysis shows a significant 4th order contrast for the elevation marginal mean error with the azimuth direction. A typical plot
of the elevation error marginal means for the display column effect and display row effect is shown in figure 24.

![Figure 24 – Typical marginal mean absolute elevation errors relative to the elevation direction and the azimuth direction.](image)

**Absolute Distance Error**

The marginal mean error for each group is shown in figure 25. The distribution of the error for the absolute error for all three groups is shown in figure 26. The data is not normally distributed so a generalized linear model is used where a gamma distribution with a log link is defined.
Figure 25 – Marginal mean absolute distance error for each group. The blind group is statistically different from the sighted and blindfolded groups. There is no statistically significant difference between the sighted and blindfolded groups.

Figure 26 – Histogram showing the distribution of absolute error for all groups.

The test shows that the group (p = 0.000), trial (p = 0.00), row (p = 0.000), column (p = 0.000) are all main effects. There are also interaction effects of row*column (p = 0.000), group*column (p = 0.000) and group*row (p = 0.000). Table 5 summarizes the data of the GLM analysis. The analysis indicates a significant marginal mean difference in a pairwise comparison between Groups 1 and 3 and Groups 2 and 3. A significant mean difference was not seen between Groups 1 and 2. The data is summarized in table 6.
Table 5 – Summary of GLM analysis data in absolute distance error

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Table 6 – Pairwise comparison of group in absolute distance error

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<th>df</th>
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Contrast analysis of the data shows significant shapes of error in the azimuth and elevation directions. The contrast analysis shows a significant quadratic contrast for the absolute marginal mean error with the elevation direction. The contrast analysis shows a significant 4th order contrast for the elevation marginal mean error with the azimuth direction. A typical plot of the distance error marginal means for the display column effect and display row effect is shown in figure 27.
Data Variability Analysis

The participants’ performance was also measured as a function of the variability in the error. The data that was used for the variability data was the relative error data that contained the information on whether the subject was looking left or right of the target. The data had a normal distribution shape. The variability term was determined for each subject by their standard deviation of the azimuth error, the elevation error. A test for homogeneity of variance was used to test the assumption of equal variance among groups.

The head orientation vector localization points from all trials are shown in figure 28 and demonstrate the variability difference among the groups. The variability in localization is smallest for the sighted group followed by the blindfolded group and then the blind group.
Figure 28 – Head orientation localization points for all the trials. The red box indicates the physical boundaries of the acoustic display. These data represent the difference in variability among the groups. Blind subjects had the largest spatial variability and the sighted subjects the smallest.
The data was statistically analyzed for variation in azimuth and elevation error. The standard deviation in azimuth and elevation angle error for each group is shown in figure 29.

![Figure 29 – Standard deviation in azimuth angle error for each group. The Levene statistic indicated a significant difference in variation among the groups.](image)

The test for homogeneity of variance is rejected among all groups in elevation and azimuth error. By rejecting the equal variance null hypothesis, the conclusion is that there is a difference in the error variation among the groups. The Levene statistic for all groups is shown in table 6.

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<td>2</td>
<td>2653</td>
<td>.000</td>
</tr>
</tbody>
</table>
Relative Error Analysis

The data was analyzed based on the relative error of the subjects in the localization tasks. The data was shifted so that all data was positive to take advantage of the gamma distribution. The data from the azimuth error was analyzed for main effects using the generalized linear model. In this case, the main effects are row (p=0.000) and column (p=0.000) as shown in table 7. The group is not a main effect (p = .462) as the error centers around zero for all groups. The azimuth error was also analyzed for each group individually. The row and column were main effects for each group. The marginal means for each group relative to the azimuth direction is shown in figure 30. The data indicates that the subjects are underestimating the target location at the outer edges in azimuth. A similar condition is seen for the elevation error as shown in figure 31.

Table 7 – Summary of GLM analysis data in relative azimuth error. Group is not a main effect.

<table>
<thead>
<tr>
<th>Tests of Model Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>(Intercept)</td>
</tr>
<tr>
<td>Group</td>
</tr>
<tr>
<td>Row</td>
</tr>
<tr>
<td>Column</td>
</tr>
<tr>
<td>Group * Row</td>
</tr>
<tr>
<td>Group * Column</td>
</tr>
</tbody>
</table>
Temporal Analysis of Angular Path Length

The angular path length was analyzed using the GLM due to the non-parametric data. The mean angular path length in the azimuth for the sighted group was significantly different
than the other two groups in the azimuth. The angular path length for the sighted group was significantly different than the blind group in elevation. An example of the temporal data is shown in figure 32 and gives a representation of the various strategies seen in the experiment. The results are shown in table 8 and 9, and the mean angular path length for each group is shown in figure 33.

Figure 32: Typical temporal data from target 67 displaying different sweep strategies. The positional data has been normalized to the target location. Note the increased use of elevation movements in the response of the blind subject.

Table 8: Pairwise comparison of azimuth angular path length

<table>
<thead>
<tr>
<th>(I) Group</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>df</th>
<th>Sig.</th>
<th>95% Wald Confidence Interval for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>-36.27</td>
<td>17.49</td>
<td>1.00</td>
<td>0.04</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>-29.65</td>
<td>14.40</td>
<td>1.00</td>
<td>0.04</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>36.27</td>
<td>17.49</td>
<td>1.00</td>
<td>0.04</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>6.62</td>
<td>18.75</td>
<td>1.00</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>29.65</td>
<td>14.40</td>
<td>1.00</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>-6.62</td>
<td>18.75</td>
<td>1.00</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Table 9: Pairwise comparison of elevation angular path length

<table>
<thead>
<tr>
<th>(i) Group</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>df</th>
<th>Sig.</th>
<th>95% Wald Confidence Interval for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2</td>
<td>-5.73</td>
<td>5.01</td>
<td>1.00</td>
<td>0.25</td>
<td>-15.55 4.09</td>
</tr>
<tr>
<td>1 3</td>
<td>-22.10</td>
<td>10.51</td>
<td>1.00</td>
<td>0.04</td>
<td>-42.70 -1.50</td>
</tr>
<tr>
<td>2 1</td>
<td>5.73</td>
<td>5.01</td>
<td>1.00</td>
<td>0.25</td>
<td>-4.09 15.55</td>
</tr>
<tr>
<td>3 1</td>
<td>-16.37</td>
<td>10.08</td>
<td>1.00</td>
<td>0.10</td>
<td>-36.12 3.38</td>
</tr>
<tr>
<td>3 2</td>
<td>22.10</td>
<td>10.51</td>
<td>1.00</td>
<td>0.04</td>
<td>1.50 42.70</td>
</tr>
<tr>
<td>2</td>
<td>16.37</td>
<td>10.08</td>
<td>1.00</td>
<td>0.10</td>
<td>-3.38 36.12</td>
</tr>
</tbody>
</table>

Figure 33: Mean path length covered in azimuth and elevation up to button push. The azimuth data revealed a statistically significant difference between the sighted group and the blindfolded and blind groups. No significant difference was seen between the blindfolded and blind group in the azimuth. The only statistically significant difference in the elevation data was between the sighted and blind groups.

Temporal Analysis of Directional Transitions

The directional transition data was analyzed using the Poisson distribution. The trend is similar to that of the angular path length data. The mean direction transition in the azimuth for
The sighted group was significantly different than the other two groups in the azimuth as shown in Table 10. The mean directional transition for the sighted group was significantly different than the blind group in elevation. There was not a significant difference in the elevation group. The results are shown in Table 10 and 11, and the mean angular path length for each group is shown in Figure 34.

Table 10: Pairwise comparison of azimuth directional transitions

<table>
<thead>
<tr>
<th>(I) Group</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>df</th>
<th>Sig.</th>
<th>95% Wald Confidence Interval for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2</td>
<td>-1.27a</td>
<td>.615</td>
<td>1</td>
<td>.039</td>
<td>.07 -2.48 -0.07</td>
</tr>
<tr>
<td>3</td>
<td>-1.16a</td>
<td>.524</td>
<td>1</td>
<td>.027</td>
<td>-2.19 -0.13</td>
</tr>
<tr>
<td>2 1</td>
<td>1.27a</td>
<td>.615</td>
<td>1</td>
<td>.039</td>
<td>.07 2.48</td>
</tr>
<tr>
<td>3</td>
<td>.11</td>
<td>.645</td>
<td>1</td>
<td>.860</td>
<td>-1.15 1.38</td>
</tr>
<tr>
<td>3 1</td>
<td>1.16a</td>
<td>.524</td>
<td>1</td>
<td>.027</td>
<td>.13 2.19</td>
</tr>
<tr>
<td>2</td>
<td>-.11</td>
<td>.645</td>
<td>1</td>
<td>.860</td>
<td>-1.38 1.15</td>
</tr>
</tbody>
</table>

Table 11: Pairwise comparison of elevation directional transitions

<table>
<thead>
<tr>
<th>(I) Group</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>df</th>
<th>Sig.</th>
<th>95% Wald Confidence Interval for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2</td>
<td>-.67</td>
<td>.520</td>
<td>1</td>
<td>.199</td>
<td>-1.69 .35</td>
</tr>
<tr>
<td>3</td>
<td>-.83</td>
<td>.621</td>
<td>1</td>
<td>.179</td>
<td>-2.05 .38</td>
</tr>
<tr>
<td>2 1</td>
<td>.67</td>
<td>.520</td>
<td>1</td>
<td>.199</td>
<td>-.35 1.69</td>
</tr>
<tr>
<td>3</td>
<td>-.17</td>
<td>.586</td>
<td>1</td>
<td>.778</td>
<td>-1.31 .98</td>
</tr>
<tr>
<td>3 1</td>
<td>.83</td>
<td>.621</td>
<td>1</td>
<td>.179</td>
<td>-.38 2.05</td>
</tr>
<tr>
<td>2</td>
<td>.17</td>
<td>.586</td>
<td>1</td>
<td>.778</td>
<td>-.98 1.31</td>
</tr>
</tbody>
</table>
Figure 34: Mean path length covered in azimuth and elevation up to button push. The azimuth data revealed a statistically significant difference between the sighted group and the blindfolded and blind groups. No significant difference was seen between the blindfolded and blind group in the azimuth. No significant difference was seen in the elevation data among the groups.

Time in Localization

The subjects were not given instructions in the amount of time to spend on the localization task or initiation following acoustic cue. As a result, they are considered to have acted at a self-selected pace. The angular path length was analyzed using the GLM due to the non-parametric data using the gamma distribution. A significant difference was seen between group 1 and the other two groups as shown in table 12 and figure 35.
Table 12: Pairwise comparison of time to button pushes in auditory localization

<table>
<thead>
<tr>
<th>(I) Group</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>df</th>
<th>Sig.</th>
<th>95% Wald Confidence Interval for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>-4.45</td>
<td>0.75</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>-6.45</td>
<td>1.91</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4.45</td>
<td>0.75</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>-2.00</td>
<td>1.83</td>
<td>1.00</td>
<td>0.28</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>6.45</td>
<td>1.91</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2.00</td>
<td>1.83</td>
<td>1.00</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Figure 35: Mean path length covered in azimuth and elevation up to button push. A statistically significant difference was revealed between the sighted group and the blindfolded and blind groups.

Angular/Positional Drift

Drift was assessed on all 16 subjects. The results from the run sequence linear regression are shown in table 13 and figure 36. One subject had a drift in the residual of 10° from the first target to the last target. The average absolute drift was 1.96°.
Table 13: Drift in residual over course of experiment for each subject

<table>
<thead>
<tr>
<th>Subject</th>
<th>Drift (deg)</th>
<th>Group</th>
<th>Abs Drift (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.18</td>
<td>1</td>
<td>1.09</td>
</tr>
<tr>
<td>2</td>
<td>-0.55</td>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
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<td>-2.41</td>
<td>3</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>10.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-0.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-4.13</td>
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<td></td>
</tr>
<tr>
<td>9</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>-0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>4.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>-0.55</td>
<td></td>
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</tr>
<tr>
<td>Avg</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>0.68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 36: Typical run sequence plot used to assess drift in the subjects localization error over the course of the experiment. The linear regression line indicates a slight negative drift in error.
Discussion

Part 1 of this experiment was designed to characterize the relationship between visual point-of-gaze and head orientation during acoustic target localization in normally sighted subjects. In all studies, the participants were given specific instructions to direct their head vector and fixate their eye gaze at the indicated target. If the participants were able to follow instructions, then the location of the eye gaze fixation and the head direction vector should correlate. The data from the experiment shows that there is a minimum error between the location to which the participants are directing their eye gaze, and the direction they are aiming their head direction vector. When given specific instructions, sighted subjects were able to orient their head to the same location as their eye gaze. The data shows a slight delay as the subject saccades to the location and the head rotates to align the eyes to a neutral eye-in-head angle. Previous research has shown that subjects are reliably and accurately able to fixate on targets with their eye gaze. Therefore, the conclusion from part 1 is that the subjects’ ability to localize targets can be measured based on the subjects’ head orientation vector.

The primary goal of part 2 was to measure the groups’ relative abilities to localize spatial auditory targets. The measure of the subjects’ ability was based on the azimuth head vector error, elevation head vector error, and the absolute radial error. The analysis also examined the temporal differences among the groups.
The results from the absolute error and error variability indicate that the sighted subjects are better able to localize the auditory targets compared to the blindfolded sighted subjects. Although both subject groups had no visual deficits, the data suggest that a visual reference provides a person with assistance in localizing spatial targets and the results agree with other reports (Shelton & Searle, 1980). The study space had a defined area in which the subjects were required to localize the targets. Both groups were directed identically to the center of the study space, but the sighted group was able to restrict their field of localization within the borders of the study space. The statistically significant difference in the error is in part due to the variability of the errors made in each group. Figure 28 showed the head vector point of intersection for Groups 1 and 2 where the variability of the data for Group 2 is much larger than that of Group 1. This is also shown in the data variability analysis for each group. The variation for Group 2 (9.2°) was significantly larger (p<.027) than that of Group 1 (4.8°). Prior studies have suggested that vision can improve localization by giving a context to the area in which the auditory localizations are made (S. Getzmann, 2005).

Because people who are blind are forced to use their hearing more for spatial navigation, the hypothesis was that they would be better able to localize the sounds. Contrary to the hypothesis, the results of the study showed that the blindfolded sighted subjects were better able to localize the spatial auditory targets in comparison to the blind group. However, Group 2 is statistically significantly better than Group 3 in the azimuth angle errors (mean marginal difference of 3.99°), elevation errors (4.99°), and the absolute radial error (0.21°). The blind population has a much larger deviation in their precision of localization of the spatial targets. The variability of error is also statistically larger for the blind population (standard
deviation 13.7°) as compared to the sighted (5°) and blindfolded (10°) groups. The reason for the increased error may be due to the lack of visual reference similar to what was seen when comparing the sighted and blindfolded groups. This explanation is more plausible for the statistical difference in error between Group 1 and 3. However, neither Group 2 nor 3 has a visual reference for the specific study. Care was taken to ensure that the blindfolded subject never saw the study space prior to the experiment. Previous reports have shown that early blindness could lead to decreased spatial awareness (Thinus-Blanc & Gaunet, 1997). Results seem to be mixed on the impact on locomotor tasks that uses spatial inference (Loomis, Golledge, & Klatzky, 1998). The results from this study indicate that blindfolded subjects perform better due to their visual spatial perspective. This perspective provides important exteroceptive feedback about the body’s position in relation to the location of other external objects.

The relative error analysis shows that in the periphery of the study space, the groups, on average, underestimated the position of the target and instead preferred to restrict their localization to the space directly in front of them. This relative error analysis shows that the subjects maintain a body-centered orientation in the azimuth and the elevation. There was initial concern that the calibration space was distorting the periphery. However, these results are consistent with results found in previous work and recreated in Figure 37. The azimuth range reported in the previous research is much larger than the data from this study and is only in the azimuth; however, the results show a similar trend with the subjects underestimating the position along the periphery.
Figure 37: Similar results to the found in this experiment showing underestimation when moving from the CL in the azimuth. Recreated (Lewald, Dörscheidt, & Ehrenstein, 2000)

The results showed that the blindfolded and blind individuals responded very differently than the sighted individuals in their strategy to localize the auditory sound. Both the blindfolded and the blind subjects performed longer sweeps of the display area, and had more direction transitions than the sighted group. Presumably, this is intended to help with localization by shifting of ITD and IID differentials between the ears. The results also indicated that the blind group had a greater sweep angle in the elevation and could be as a result of a strategy that has been developed through experience or training. The blindfolded and blind groups also spent much more time on each trial compared to the sighted group. Interestingly, the strategy did not result in better localization errors. Again, it appears that visual context provides an advantage in localization of auditory targets.
One limitation of this experiment was the age discrepancy among the groups. Hearing ability is known to drop off with age due to various factors including presbycusis and noise-related hearing loss. Figure 38 gives a general trend in hearing capability in relation to age.

![Figure 38: Hearing loss related to age. Recreated (Chaix, 6/17/13)](image)

Because the average age of the blind group was 53, the chart indicates that mild to moderate hearing loss is likely above the 4K Hz frequency range. For this reason, the frequency cues that are important to localization in the azimuth (ILD up to 1500Hz, IID above 800 Hz) should still be within the normal range for the blind group. The results from the localization in the azimuth should be valid. The pinna cues however require higher frequencies and the elevation discernment of the blind and blindfolded group may be impaired due to the age. An exacerbating factor is the use of the pink noise in the study. The spectral power drops off with increasing frequency and further impairs their ability to localize the sound. Therefore, further
work, with age matched subjects and white noise sound sources, would be required to test the validity of these results.

Another issue noted in the temporal data was the appearance of drift in the subjects’ orientation. Although the majority of subjects maintained a centered position, one subject drifted by 10°. The subjects were positioned with their feet within the legs of the table to help with proprioceptive alignment. Between trials, the subjects were realigned if necessary during sensor setup and the acclimation phase. Although attempts were made to keep the subjects oriented towards the board, it is not surprising that the blindfolded and blind groups have larger average drift due to the lack of visual context.

In order to improve future experiments, several modifications should be considered. The subjects should be age matched to ensure that age related hearing issues are controlled. The subjects should also be tested for hearing ability. White noise sound source should also be used to prevent any loss of elevation cues. The random sequence of speaker activation should also be the same for each participant. This would allow for more thorough analysis of temporal-spatial differences among the groups since the spatial distances between target pairs would be consistent across all subjects.

Several conclusions can be made using the findings of this experiment for development of a better navigation tool for the blind. First, when a navigation tool is designed and tested, the device must be designed for and tested on blind individuals. The results have shown that people who are blind behave differently when investigating their environment while localizing spatial sounds. In many situations, designers may be sighted and are more familiar with their
visual spatial world and may not fully appreciate the challenges facing the blind population. A good example of the differences was seen in the temporal data. The path length, number of transitions, and time taken were all greater in the blind group compared to the sighted group. Another factor is the tendency of individuals to focus towards the direction the body is facing. The errors along the edge of the board indicated that the subjects were underestimating the location of peripheral targets. This trend was similar among all groups. A person who is blind may be hesitant to turn his head away from his body direction when exploring his environment while navigating due to an increased amount of disorientation to the vestibular system. The white cane may be ideal to many blind subjects because they can explore their environment while maintaining fairly stable head position. The blind subjects also experienced the most drift. Studies have shown that an external frame of reference is crucial in recalibrating the internal sense of spatial orientation. (Souman, Frissen, Sreenivasa, & Ernst, 2009) A navigation tool that would aid the person in maintaining a centered orientation could potentially be very helpful.

A next step in the research would be to assess the tracking of moving spatial auditory targets. Due to the design of the controls and spacing of the speakers, the program could be configured to create virtual auditory motion. One study of interest would be to investigate representational momentum in the blind population. Due to their lack of spatial knowledge, people that are blind may not experience the ‘momentum’ effect as sighted people do. Representational momentum refers to the phenomenon of predicting or expecting where a target will be located at a certain time, such as where a thrown ball lands on the ground, based on its previous position in space, such as at the apex of the throw (S. Getzmann, Lewald, &
Guski, 2004). Subjects in that study were able to predict with some accuracy the final stopping point of a moving auditory target based on the perceived trajectory pattern. This concept becomes relevant for aiding in blind navigation such as if a blind person were wearing a device with audible cues for moving obstacles (other people walking or stationary objects the blind person is approaching) and would be able to predict their trajectory, thus avoiding contact.

Recently, researchers had success with a wearable device guiding blind people through a walking course using simple vibrotactile and auditory cues. These signals were provided by a wrist sensor and a directional compass worn on a visor (Marston, Loomis, Klatzky, & Golledge, 2007). The use of spatialized sound and synthesized speech in the form of vocal commands have been used to guide blind people through familiar and unfamiliar environments, with the spatialized sound being more effective for accurate navigation (Loomis, Klatzky, & Golledge, 2001). Another next step in this research would be to investigate the effect of noise when localizing spatial targets. In helping develop better navigation aids, this may be especially crucial in that the subjects would be navigating in noisy environments.

Information gathered in this study may lead to advancements in ambulatory aides for the blind and especially wearable devices providing haptic and auditory feedback representing obstacles in the immediate environment.
List of References
List of References


Appendix 1

Ascension Flock of Birds

**Technical**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking Range:</td>
<td>• Mid-Range Transmitter: ±30° (.75m) for specified accuracy; ±36° (9m) for slightly reduced accuracy.</td>
</tr>
<tr>
<td></td>
<td>• Extended-Range Transmitter: ±6-10’ (2.4-3.05m) depending on environmental conditions.</td>
</tr>
<tr>
<td>Angular Range:</td>
<td>±180° Azimuth &amp; Roll, ±90° Elevation</td>
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<tr>
<td>Static Accuracy:</td>
<td>Position: 0.07” (1.8mm) RMS</td>
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<tr>
<td>Orientation:</td>
<td>0.5° RMS</td>
</tr>
<tr>
<td>Static Resolution:</td>
<td>Position: 0.02” (0.5mm) @ 12” (30.5cm)</td>
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<tr>
<td>Orientation:</td>
<td>0.1” @ 12” (30.5cm)</td>
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<td>Update Rate:</td>
<td>Up to 144 measurements/second</td>
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<tr>
<td>Outputs:</td>
<td>X, Y, Z positional coordinates and orientation angles, or rotation matrix</td>
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<tr>
<td>Interface:</td>
<td>RS-232 with selectable baud rates to 115,200</td>
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<td>Format:</td>
<td>Binary</td>
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<tr>
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**Physical**

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<tbody>
<tr>
<td>Transmitters:</td>
<td>• Mid-Range Transmitter 3.75” (9.6cm) cube with 10’ (3.05m) cable; or</td>
</tr>
<tr>
<td></td>
<td>• Extended-Range Transmitter: 12” (30.5cm) cube with 20’ (6.1m) cable</td>
</tr>
<tr>
<td>Sensor:</td>
<td>1.0” x 1.0” x 0.8” (25.4mm x 25.4mm x 20.3mm) cube or in optional 3D Pointer (&quot;Wands&quot;) with 10’ (3.05m) or 35’ (10.7m) cable</td>
</tr>
<tr>
<td>Enclosure:</td>
<td>9.5” x 11.5” x 2.6” (24cm x 29cm x 6.6cm)</td>
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<tr>
<td>Power:</td>
<td>User provided or optional external plug-in, US/European version</td>
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<tr>
<td>Operating Temperature:</td>
<td>10°C to 40°C (50°F to 104°F)</td>
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<td>Operating Humidity:</td>
<td>10% to 90% non-condensing</td>
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* Accuracy verified over range from 20.3cm to 76.2cm at constant orientation with Mid-Range Transmitter.
Appendix 2

Eyelink II

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<td><strong>Monocular Sampling Rate</strong></td>
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<td><strong>Binocular Sampling Rate</strong></td>
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<td><strong>Eye Tracking Principle</strong></td>
<td>Pupil Only (500Hz)</td>
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<td>Pupil with CR (250Hz)</td>
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<tr>
<td><strong>Average Accuracy</strong></td>
<td>&lt;0.5° typical</td>
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<tr>
<td><strong>Saccade Event Resolution</strong></td>
<td>0.05° microsaccades</td>
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<tr>
<td><strong>Spatial Resolution (RMS)</strong></td>
<td>0.01° Dark Pupil</td>
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<tr>
<td></td>
<td>0.025° Pupil-CR mode</td>
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<td><strong>End to End Sample Delay</strong></td>
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<td><strong>Blink Recovery Time</strong></td>
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<td><strong>Pupil Detection Models</strong></td>
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<td>36° vertically</td>
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<td><strong>Allowable Head Movement</strong></td>
<td>±/−30° display</td>
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<td><strong>Optimal Camera-Eye Distance</strong></td>
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<td><strong>Infrared Wavelength</strong></td>
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### SPECIFICATIONS

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<td>Max Input Power</td>
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### NOTES:

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. SPECIFICATIONS SUBJECT TO CHANGE OR WITHDRAW WITHOUT NOTICE.
3. THIS PART IS ROHS 2002/95/EC COMPLIANT.

---

### REVISION HISTORY

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<td>10/27/2014</td>
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Appendix 4

Toshiba Photocoupler

Toshiba TLP222G, TLP222G-2

Cordless Telephones
PBX
Modems

The Toshiba TLP222G series consist of a gallium arsenide infrared emitting diode optically coupled to a photo-MOSFET in a DIP package. The TLP222G series are a bi-directional switch, which can replace mechanical relays in many applications.

- TLP222G: 4-pin DIP (P/N), 1-channel type (1-form A)
- TLP222G-2: 8-pin DIP (P/N), 2-channel type (2-form A)
- Peak OFF-state voltage: 350 V (max)
- Trigger LED current: 8 mA (max)
- Operating current: 120 mA (max)
- OFF-state resistance: 35 kΩ (max, 1 × 3 Ω)
- On-state resistance: 50 kΩ (max, continuous)
- Isolation voltage: 2500 Vrms (min)

Pin Configuration (top view)

Weight: 0.20 g (typ.)

Toshiba 11-082

2002-04-19
## Appendix 5

6509 DIO Card

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Appendix 6

Labview

LabView Auditory Control Front Panel

![LabView Auditory Control Front Panel](image1)

LabView Auditory Control Block Diagram

![LabView Auditory Control Block Diagram](image2)
## Appendix 7

### Participants

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### Appendix 8

DIO 6509 Target Position and Wiring

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Appendix 9

MATLAB code for data processing

Auditory Targets - Sighted

clear

%%%Read in file folder
myFolder = '\Audio\';%File path with target localization data
if ~isdir(myFolder)
    errorMessage = sprintf('Error: The following folder does not exist:
%s', myFolder);
    uiwait(warndlg(errorMessage));
    return;
end
filePattern = fullfile(myFolder, 'rwn*.xlsx');
expFiles = dir(filePattern);

for k = 1:length(expFiles)
    i = k;
    baseFileName = expFiles(k).name;
    fullFileName = fullfile(myFolder, baseFileName);
    M{i} = xlsread(fullFileName);
end
clear baseFileName fullFileName expFiles filePattern i k errorMessage

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Read in Target Matrix
TpFile = xlsread('91 Audio Targets.xlsx');%File with target data
Tp = TpFile(:,1:5);

k=1;
filePattern = fullfile(myFolder, '*order*.xlsx');
expFiles = dir(filePattern);
baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);
Tl = xlsread(fullFileName);

k=1;
filePattern = fullfile(myFolder, '*Mod*.xlsx');
expFiles = dir(filePattern);
baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);

HdMod = xlsread(fullFileName);
clear filePattern expFiles baseFileName fullFileName k

%Collect all data
%list and target position
for k = 1:length(M);

%Remove additional columns
M1{k} = M{k};
M1{k}(:,2:7) = [];
M1{k}(:,16:18)=[];
M1{k}(:,49:52)=[]
I = find(M1{k}(:,49)<3); % Find times of button push

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Mark for Temporal or Spatial Error
Temporal = 1
if Temporal == 1    % data for temporal analysis
    I2 = min(I);
    I3 = min(I)+T;
    %Select rows where button is pushed
    %All rows
    M1{k} = [M1{k}(::,:)];
end
BP = M1{k}(:,49);
if Temporal == 0  % data for error analysis
    if min(I) < 125
        T = min(I)-1;
    else
        T = 125;
    end
    I2 = min(I)-T;
    I3 = min(I)+T;
    M1{k} = [M1{k}(I2:I3,:)];
end

%Add target data to the Matrix
L = length(M1{k}(::,23)); %Length of current matrix
r = Tl(k,4); %Determine xyz position of target from
position vector
Target = r * ones(L,1); %Place the target number in the matrix
Tpx = Tp(r,1)*ones(L,1); %X position of current target
Tpy = Tp(r,2)*ones(L,1); %Y position of current target
Tpz = Tp(r,3)*ones(L,1); %Z position of current target
Row = Tp(r,4)*ones(L,1); %Row of the target
Column = Tp(r,5)*ones(L,1); %Column of the target
M1{k} = [M1{k},Target,Tpx,Tpy,Tpz,Row,Column];
Mt = M1{k};
TargetIndex = Tl(k,3);
TargetOrder = TargetIndex*ones(L,1);
HdErrorX = HdMod(1,1)*ones(L,1);
HdErrorY = HdMod(1,2)*ones(L,1);
HdErrorZ = HdMod(1,3)*ones(L,1);

%Manipulate Data

EL = Mt(:, 16:18);   %Left eye position
ER = Mt(:, 19:21);  %Right eye position
EAvg = (EL + ER)/2;  %Calculate the average eye position
TP = Mt(:,57:59);   %Target position XYX coordinates
TGAvg = TP - EAvg;   %Actual Vector from Eye CL to Target
TGAvgR = TP - ER;    %Actual Vector from Rt Eye  to Target
TGAvgL = TP - EL;    %Actual Vector from Lt Eye  to Target
EGL = Mt(:, 22:24);     %Actual Gaze from left eye
EGR = Mt(:, 25:27);     % Actual Gaze from right eye
EGAvg = [(EGL + EGR)/2];  % Average binocular gaze
EGAvg = [EGAvg(:,1)*1, EGAvg(:,2), EGAvg(:,3)];
BF = Mt(:,28:30);
BGAvg = BF - EAvg;   %Gaze vector from binocular focal point

TGAvgXYM = (TGAvg(:,1).^2+TGAvg(:,2).^2).^0.5; %XYMag of target vector
EGAvgXYM = (EGAvg(:,1).^2+EGAvg(:,2).^2).^0.5; %XYMag of gaze vector
AbXYError =
    radtodeg(acos(((TGAvg(:,1).*EGAvg(:,1))+(TGAvg(:,2).*EGAvg(:,2)))./(TGAvgXYM.*EGAvgXYM)));

TGAvgZYM = (TGAvg(:,3).^2+TGAvg(:,2).^2).^0.5; %ZYMag of gaze vector
EGAvgZYM = (EGAvg(:,3).^2+EGAvg(:,2).^2).^0.5; %ZYMag of gaze vector
AbZYError =
    radtodeg(acos(((TGAvg(:,3).*EGAvg(:,3))+(TGAvg(:,2).*EGAvg(:,2)))./(TGAvgZYM.*EGAvgZYM)));

%Calculate the point on gaze vector where the error is minimum (calculate
%the orthogonal projection from the gaze vector)
ScalProj = dot(TGAvg,EGAvg,2); % Resturns the scaler projection magnitude for
minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
PGAvg = EGAvg.*SP; %Scaled Gaze Vector
EstGPt = EAvg + PGAvg; %XYZ coordinates of point along gaze vector with
minimum error
ErrorXYZ = (TP - EstGPt)*100; %Error to the actual target position
ErrorMag = sqrt(sum((ErrorXYZ'.^2))'); %Magnitude of error

% Pointer Data

PtrAV = Mt(:,13:15)-Mt(:,10:12);
PtrAVMag = sqrt(sum((PtrAV'.^2))');
ptrAV = PtrAV ./ [PtrAVMag,PtrAVMag,PtrAVMag];
PtrTV = TP - Mt(:,10:12);
PtrTVAvgXYM = (PtrTV(:,1).^2+PtrTV(:,2).^2).^0.5; %XYMag of pointer to target pointer vector
PtrAVAvgXYM = (PtrAV(:,1).^2+PtrAV(:,2).^2).^0.5; %XYMag of actual pointer vector
AbPtrXYError = radtodeg(acos(((PtrTV(:,1).*PtrAV(:,1))+(PtrTV(:,2).*PtrAV(:,2)))./(PtrTVAvgXYM.*PtrAVAvgXYM)));% XY angle error

ScalProj = dot(PtrTV,ptrAV,2); % Resturns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
PtPGAvg = ptrAV.*SP; %Scaled Pointer Vector
PtEstGPt = Mt(:,10:12) + PtPGAvg; %XYZ coordinates of point along pointer vector with minimum error
PtErrorXYZ = (TP - PtEstGPt)*100; %Error to the actual target position
PtErrorMag = sqrt(sum((PtErrorXYZ'.^2)))';
PtEstMag = 1.136 - Mt(:,11); % Distance from Board Plane to head
PtEstScl = PtEstMag ./ ptrAV(:,2); %Scaler to have Y head vector intersect plane
PtEstGz = ptrAV.*[PtEstScl,PtEstScl,PtEstScl] + Mt(:,10:12);

%Head Vector

HdError = [HdErrorX,HdErrorY,HdErrorZ];
HdAVa = Mt(:,4:6)-Mt(:,7:9);
HdAVMag = sqrt(sum((HdAVa'.^2))');
HdAVMag2 = HdAVMag / 2;
hdAV = hdAVa ./ [HdAVMag,HdAVMag,HdAVMag];
HdOPos = Mt(:,4:6) - hdAV.*[HdAVMag2,HdAVMag2,HdAVMag2];
HdNPos = HdOPos + HdError;
HdAV = Mt(:,4:6)-HdNPos;
HdAVMag = sqrt(sum((HdAV'.^2))');
HdAVMag2 = HdAVMag / 2;
hdAV = hdAVa ./ [HdAVMag,HdAVMag,HdAVMag];
HdTVAvgXYM = (HdTV(:,1).^2+HdTV(:,2).^2).^0.5; %XYMag of head to target pointer vector
HdAVAvgXYM = (HdAV(:,1).^2+HdAV(:,2).^2).^0.5; %XYMag of actual pointer vector
AbHdXYError = radtodeg(acos(((HdTV(:,1).*HdAV(:,1))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgXYM.*HdAVAvgXYM)));% XY angle error
ScalProj = dot(HdTV,hdAV,2); % Resturns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
HdPGAvg = hdAV.*SP; %Scaled Pointer Vector
HdEstGPt = HdNPos + HdPGAvg; %XYZ coordinates of point along pointer vector with minimum error
\begin{verbatim}
HdErrorXYZ = (TP - HdEstGpT)*100; %Error to the actual target position
HdErrorMag = sqrt(sum((HdErrorXYZ).^2));
HdEstMag = 1.136 - HdNPos(:,2); % Distance from Board Plane to head
HdEstScl = HdEstMag./hdAV(:,2); % Scaler to have Y head vector intersect plane
HdEstGz = hdAV.*[HdEstScl,HdEstScl,HdEstScl] + HdNPos;
% Check = [HdEstGz];

% Direction of Error: Underestimation is negative
if TGAvg > 0
    if ErrorXYZ(:,1) > 0
        XYErrorOU = -AbXYError;
    else
        XYErrorOU = AbXYError;
    end
else
    if ErrorXYZ(:,1) < 0
        XYErrorOU = -AbXYError;
    else
        XYErrorOU = AbXYError;
    end
end
if TGAvg > 0
    if ErrorXYZ(:,3) > 0
        ZYErrorOU = -AbZYError;
    else
        ZYErrorOU = AbZYError;
    end
else
    if ErrorXYZ(:,3) < 0
        ZYErrorOU = -AbZYError;
    else
        ZYErrorOU = AbZYError;
    end
end
if ErrorXYZ(:,1) > 0
    XYError = +AbXYError;
else
    XYError = -AbXYError;
end
if ErrorXYZ(:,3) > 0
    ZYError = AbZYError;
else
    ZYError = -AbZYError;
end
% for the pointer
if TGAvg > 0
    if PtErrorXYZ(:,1) > 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
else
    if PtErrorXYZ(:,1) < 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
end
\end{verbatim}
else
    PtXYErrorOU = AbPtrXYError;
end

if PtErrorXYZ(:,1) > 0
    PtXYError = AbPtrXYError;
else
    PtXYError = -AbPtrXYError;
end

%for the head
if TGAvg > 0
    if HdErrorXYZ(:,1) > 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
else
    if HdErrorXYZ(:,1) < 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
end

if TGAvg > 0
    if HdErrorXYZ(:,3) > 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
else
    if HdErrorXYZ(:,3) < 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
end

if HdErrorXYZ(:,1) > 0
    HdXYError = AbHdXYError;
else
    HdXYError = -AbHdXYError;
end
if HdErrorXYZ(:,3) > 0
    HdZYError = AbHdZYError;
else
    HdZYError = -AbHdZYError;
end

%Error from individual eyes
%Right
    ScalProjR = dot(TGAVgR,EGR,2); % Resturns the scaler projection magnitude
  for minimum error
    SPR = [ScalProjR,ScalProjR,ScalProjR]; %Matrix formatting for multiplication
PAvgR = EGR.*SP; %Scaled Gaze Vector
EstGR = ER + PAvgR; %XYZ coordinates of point along gaze vector with minimum error
ErrorR = (TP - EstGR)*100; %Error to the actual target position
ErrorMagR = sqrt(sum((ErrorR'.^2))'); %Magnitude of error

%Left
ScalProjL = dot(TGAvgL,EGL,2); % Resturns the scaler projection magnitude for minimum error
SPL = [ScalProjL,ScalProjL,ScalProjL]; %Matrix formatting for multiplication
PAvgL = EGL.*SP; %Scaled Gaze Vector
EstGL = EL + PAvgL; %XYZ coordinates of point along gaze vector with minimum error
ErrorL = (TP - EstGL)*100; %Error to the actual target position
ErrorMagL = sqrt(sum((ErrorL'.^2))'); %Magnitude of error

%Calculate the X and Z positions at the point where the gaze vector crosses the plane (assuming Y = 0.99)
EstMag = 1.136 - EAvg(:,2); % Distance from Avg Eye Pos to board plane
EstScL = EstMag ./ EGAvg(:,2); %Scaler to have Y Gze vector intersect plane
EstGz = EGAvg.*[EstScL,EstScL,EstScL] + EAvg; %Point where crosses Y plane

%Format and redefine matrices

clear EL ER EGL EGR SP BGAvg
MT2{k} = [Mt, TGAvg, EGAvg, PGAvg, ScalProj, EstGpt, ErrorXYZ, ErrorMag, AbXYError, XYError, XYErrorOU, AbZYError, ZYError, ZYErrorOU, AbPtrXYError, EstGz, ErrorR, ErrorL, PtErrorXYZ, AbHdXYError, HdXYError, AbHdXYError, HdXYError, AbHdZYError, HdZYError, AbHdZYError, HdZYErrorOU, HdZEstGz, PtEstGz, TargetOrder];
Mtest = [Mt, TGAvg, EGAvg, ScalProj, EstG, Error, ErrorMag, EstGz, ErrorR, ErrorL];
HDVTR{k} = [Target, BP, HdErrorXYZ, AbHdXYError, HdXYError, AbHdZYError, HdZYError, HdXYErrorOU, HdZYErrorOU, HdEstGz]; %Matrix for temporal analysis

%Moving average for determining closest value
X = 1;
if X == 1
A = 25;
Average = tsmovavg(MT2{k}(:,78),'s',A, 1); %'A' point moving average
[J,ri] = min(Average(:,1)); %Find row index (ri) of minimum value moving average
MT2{k} = MT2{k}(ri-(A-1):ri,:); %Select 'A' prior rows from the matrix
H{k} = [ri(1,1)]; %Log the selected row indices
end
MSTDAz{k} = std(MT2{k}(:,79));
MSTDEl{k} = std(MT2{k}(:,81));

if MSTDAz{k}(1,1) > 0.25
    MTS{k} = [];
    Y=1;
elseif MSTDEl{k}(1,1) > 0.25
    MTS{k} = [];
    Y=1;
else
    MTS{k} = MT2{k};
    Y=0;
end

if Y==0
    MErr{k} = mean(MTS{k}(:,:));
    MStd{k} = std(MTS{k}(:,:));
    MR{k} = range(MTS{k}(:,:));
else
    MErr{k} = [];
    MStd{k} = [];
    MR{k} = [];
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Code to calculate the transition points
% Azimuth Transitions
MPlot = HDVTR{k};
MPlotT{k} = MPlot;

BPmin2 = min(find(MPlot(:,2)<3));
if min(MPlot(:,2)>3)
    Test = 1
    BPmin2 = length(MPlot(:,2))
end

LTH = length(MPlot(:,1));
MPlotX = (1:LTH)/250;
v=MPlot(1:BPmin2,12);
v = round(v*1000)/1000;
v1=v;
x = MPlotX(1:BPmin2);
figure(1)
plot(x, v)
delta = 0.035;
maxtab = [];
mintab = [];
if nargin < 3
    x = (1:length(v))';
else
    x = x(:);
    if length(v)== length(x)
        error('Input vectors v and x must have same length');
    end
end
if (length(delta(:)))>1
    error('Input argument DELTA must be a scalar');
end

if delta <= 0
    error('Input argument DELTA must be positive');
end

mn = Inf; mx = -Inf;
mnpos = NaN; mxpos = NaN;
lookformax = 1;

for i=1:length(v)
    this = v(i);
    if this > mx, mx = this; mxpos = x(i); end
    if this < mn, mn = this; mnpos = x(i); end
    if lookformax
        if this < mx-delta
            maxtab = [maxtab ; mxpos mx];
            mn = this; mnpos = x(i);
            lookformax = 0;
        end
        else
            if this > mn+delta
                mintab = [mintab ; mnpos mn];
                mx = this; mxpos = x(i);
                lookformax = 1;
            end
        end
    end
end

AzMax = [maxtab];
AzMin = [mintab];
AzMaxC = size(AzMin);
AzMinC = size(AzMin);

% Elevation Transitions
v=MPlot(1:BPmin2,14);
v = round(v*1000)/1000;
v = smooth(v,11);
x = MPlotX(1:BPmin2);
figure(2)
plot(x,v)
delta = 0.035;

% Eli Billauer, 3.4.05 (Explicitly not copyrighted). Modified
% This function is released to the public domain; Any use is allowed.
maxtab = [];
mintab = [];
if nargin < 3
    x = (1:length(v))';
else
x = x(:);
if length(v)~= length(x)
    error('Input vectors v and x must have same length');
end
end

if (length(delta(:)))>1
    error('Input argument DELTA must be a scalar');
end

if delta <= 0
    error('Input argument DELTA must be positive');
end

mn = Inf; mx = -Inf;
mnpos = NaN; mxpos = NaN;
lookformax = 1;

for i=1:length(v)
    this = v(i);
    if this > mx, mx = this; mxpos = x(i); end
    if this < mn, mn = this; mnpos = x(i); end

    if lookformax
        if this < mx-delta
            maxtab = [maxtab ; mxpos mx];
            mn = this; mnpos = x(i);
            lookformax = 0;
        end
    else
        if this > mn+delta
            mintab = [mintab ; mnpos mn];
            mx = this; mxpos = x(i);
            lookformax = 1;
        end
    end
end

ElMax = maxtab;
ElMin = mintab;
ElMaxC = size(ElMax);
ElMinC = size(ElMin);

TransC{k} = [Target(1:1), AzMaxC(1:1), AzMinC(1:1), ElMaxC(1:1), ElMinC(1:1)];
%Collected Transition Data

%Test = 2

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  
% Calculate Path Length  

v=MPlot(1:BPmin2,6);
BPmin2a{k} = BPmin2;
v2{k} = v;
v = round(v*1000)/1000;
v = smooth(v,11);
v1=v;

x = MPlotX(1:BPmin2);
AzPath = 0;
AzPathAbs = 0;
ElPath = 0;
ElPathAbs = 0;
m=length(v);
m1{k} = m;
% there are m-1 splines for m points
for i=1:1:m-1
%dx=xi(i+1)-xi(i);
dy= v(i+1)-v(i);
AzPathAbs = AzPathAbs + abs(dy);
AzPath = AzPath + dy;
end
AzPath2 = [AzPathAbs,AzPath, MPlotX(BPmin2)];
AzPathAbs2{k} = AzPath;
AzPath3{k} = AzPath2;

v=MPlot(1:BPmin2,8);
v = round(v*1000)/1000;
v = smooth(v,11);
x = MPlotX(1:BPmin2);

m=length(v);
% there are m-1 splines for m points
for i=1:1:m-1
%dx=xi(i+1)-xi(i);
dy2= v(i+1)-v(i);
ElPath = ElPath + dy2;
ElPathAbs = ElPathAbs + abs(dy2);
end
ElPath2 = [ElPathAbs,ElPath, MPlotX(BPmin2)];

Path{k} = [Target(1:1), AzPath2, ElPath2,TargetOrder(1:1)]; %Path Length data from each target

delclear Tpx Tpy Tpz r L k Target I2 I3 Mt ri Time T ScalProj EstMag EstScl I J ErrorR ErrorL

clear SPL SPR PGAvgL PGAvgR ScalProjL ScalProjR TGAvgL TGAvgR TP EstGL EstGR Average

clear ErrorMagL ErrorMagR EAvg EGAvg Error ErrorMag EstG EstGz A

%Convert the cell into one Matrix

MF = cell2mat(MTS');
MError = cell2mat(MErr');
MStDev = cell2mat(MStd');
MRg = cell2mat(MR');
HDVTR2 = cell2mat(HDVTR');

89
Transitions = cell2mat(TransC');
PathLength = cell2mat(Path');
MeanErr = mean(MError(:,75:82))
StdErr = std(MError(:,75:82))
MSPSS = [MError(:,56:61),MError(:,72:88),MError(:,95:115)];
TemporalData = [Transitions, PathLength];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Save the temporal data
TempDataSave = [myFolder, 'TemporalData.mat'];
save(TempDataSave, 'TemporalData'); % save the matrix
TempDataSave = [myFolder, 'HeadData.mat'];
save(TempDataSave, 'HDVTR2'); % save the matrix

Auditory Targets – Not Sighted

clear
myFolder = '\Audio\';%%Enter the path to the folder containg the audio
location files
if ~isdir(myFolder)
    errorMessage = sprintf('Error: The following folder does not exist:
%s', myFolder);
    uiwait(warndlg(errorMessage));
    return;
end
filePattern = fullfile(myFolder, 'rwn*.xlsx');
expFiles = dir(filePattern);
for k = 1:length(expFiles)
    i = k;
    baseFileName = expFiles(k).name;
    fullFileName = fullfile(myFolder, baseFileName);
    M{i} = xlsread(fullFileName);
end
clear baseFileName fullFileName expFiles filePattern i k errorMessage

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Target Matrix

TpFile = xlsread('\91 Audio Targets.xlsx'); %%Enter the path to the folder containg the SS
Tp = TpFile(:,1:5);

k=1;
filePattern = fullfile(myFolder, '*order*.xlsx');
expFiles = dir(filePattern);
baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);
T1 = xlsread(fullFileName);

k=1;
filePattern = fullfile(myFolder, '*Mod*.xlsx');
expFiles = dir(filePattern);

baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);

HdMod = xlsread(fullFileName);
clear filePattern expFiles baseFileName fullFileName k

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Append for only data during button push and add target data from Target
%list and target position
%k = 1:length(M)
for k = 1:length(M);
    %Remove additional columns
    M1{k} = M{k};
    M1{k}(:,2:7) = [];
    M1{k}(:,16:18)=[];

    % Find time of button push
    % Aligned with MM sample rate of 100 Hz
    I = find(M1{k}(:,16)<3); % Find times of button push

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Mark for Temporal or Spatial Error

Temporal = 1
if Temporal == 1    % data for temporal analysis
    I2 = min(I);
    I3 = min(I)+T;

    %Select rows where button is pushed
    %All rows
    M1{k} = [M1{k}(:,,:)];
end

BP = M1{k}(:,16);
if Temporal == 0    % data for error analysis
    if min(I) < 50
        T = min(I)-1;
    else
        T = 50;            % 30 seconds on either side of button push
    end
    I2 = min(I)-T;
    I3 = min(I)+T;
    M1{k} = [M1{k}(I2:I3,:)];
end

%Add target data to the Matrix

L = length(M1{k}(:,22));    %Length of current matrix
r = Tl(k,4);                %Determine xyz position of target from
Vector
Target = r * ones(L,1);     %Place the target number in the matrix
Tpx = Tp(r,1)*ones(L,1);    %X position of current target
Tpy = Tp(r,2)*ones(L,1);    %Y position of current target
Tpz = Tp(r,3)*ones(L,1);    %Z position of current target
Row = Tp(r,4)*ones(L,1);    %Row of the target
Column = Tp(r,5)*ones(L,1); %Column of the target
M1{k} = [M1{k},Target,Tpx,Tpy,Tpz,Row,Column];
Mt = M1{k};
TargetIndex = Tl(k,3);
TargetOrder = TargetIndex*ones(L,1);
HdErrorX = HdMod(1,1)*ones(L,1);
HdErrorY = HdMod(1,2)*ones(L,1);
HdErrorZ = HdMod(1,3)*ones(L,1);

%Manipulate Data

TP = Mt(:,24:26);   %Target position XYX coordinates
TGAvg = TP - Mt(:,4:6);     %Actual Vector from Eye CL to Target

% Pointer Data

PtrAV = Mt(:,13:15)-Mt(:,10:12);
PtrAVMag = sqrt(sum((PtrAV'.^2))');
ptrAV = PtrAV ./ [PtrAVMag,PtrAVMag,PtrAVMag];
PtrTV = TP - Mt(:,10:12);
PtrTVAvgXYM = (PtrTV(:,1).^2+PtrTV(:,2).^2).^0.5; %XYMag of pointer to target
Point vector
PtrAVAvgXYM = (PtrAV(:,1).^2+PtrAV(:,2).^2).^0.5; %XYMag of actual pointer
vector
AbPtrXYError =
radtodeg(acos(((PtrTV(:,1).*PtrAV(:,1))+(PtrTV(:,2).*PtrAV(:,2)))./(PtrTVAvgXYM.*PtrAVAvgXYM)))
ScalProj = dot(PtrTV,ptrAV,2); % Resturns the scaler projection magnitude for
minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
PtPGAvg = ptrAV.*SP; %Scaled Pointer Vector
PtEstGPT = Mt(:,10:12) + PtPGAvg; %XYZ coordinates of point along pointer
vector with minimum error
PtErrorXYZ = (TP - PtEstGPT)*100; %Error to the actual target position
PtErrorMag = sqrt(sum((PtErrorXYZ'.^2))');
PtEstMag = 1.136 - Mt(:,11); % Distance from Board Plane to pointer
PtEstScl = PtEstMag ./ ptrAV(:,2); %Scaler to have Y pointer vector intersect
plane
PtEstGz =ptrAV.*[PtEstScl,PtEstScl,PtEstScl] + Mt(:,10:12);

%Head Vector

HdError = [HdErrorX,HdErrorY,HdErrorZ];
HdAVa = Mt(:,4:6)-Mt(:,7:9);
HdAVMag = sqrt(sum((HdAVa'.^2))');
HdAVMag2 = HdAVMag / 2;
hdAV = HdAVa ./ [HdAVMag,HdAVMag,HdAVMag];
HdOPos = Mt(:,4:6) - hdAV.*[HdAVMag2,HdAVMag2,HdAVMag2];
HdNPos = HdOpos + HdError;
HdAV = Mt(:,4:6) - HdNPos;
HdAVMag = sqrt(sum((HdAV'.^2)));
HdAVMag2 = HdAVMag / 2;
hdAV = HdAV ./ [HdAVMag, HdAVMag, HdAVMag];
HdTV = TP - HdNPos;
HdTVAvgXYM = (HdTV(:,1).^2+HdTV(:,2).^2).^0.5; %XYMag of head to target pointer vector
HdAVAvgXYM = (HdAV(:,1).^2+HdAV(:,2).^2).^0.5; %XYMag of actual pointer vector
AbHdXYError = radtodeg(acos(((HdTV(:,1).*HdAV(:,1))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgXYM.*HdAVAvgXYM)));
HdTVAvgZYM = (HdTV(:,3).^2+HdTV(:,2).^2).^0.5; %ZYMag of head vector
HdAVAvgZYM = (HdAV(:,3).^2+HdAV(:,2).^2).^0.5; %ZYMag of head vector
AbHdZYError = radtodeg(acos(((HdTV(:,3).*HdAV(:,3))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgZYM.*HdAVAvgZYM))); %ZY angle error

ScalProj = dot(HdTV,hdAV,2); % Returns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; % Matrix formatting for multiplication
HdPGAvg = hdAV.*SP; % Scaled Pointer Vector
HdEstGpt = HdNPos + HdPGAvg; % XYZ coordinates of point along pointer vector with minimum error
HdErrorXYZ = (TP - HdEstGpt)*100; % Error to the actual target position
HdErrorMag = sqrt(sum((HdErrorXYZ'.^2)));
HdEstMag = 1.136 - HdNPos(:,2); % Distance from Board Plane to head
HdEstScl = HdEstMag ./ hdAV(:,2); % Scaler to have Y head vector intersect plane
HdEstGz = hdAV.*[HdEstScl,HdEstScl,HdEstScl] + HdNPos;

Check = [HdEstGz];

if TGAvg > 0
    if PtErrorXYZ(:,1) > 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
else
    if PtErrorXYZ(:,1) < 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
end

if PtErrorXYZ(:,1) > 0
    PtXYError = AbPtrXYError;
else
    PtXYError = -AbPtrXYError;
end

% for the head
if TGAvg > 0
    if HdErrorXYZ(:,1) > 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
else
    if HdErrorXYZ(:,1) < 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
end
if TGAvg > 0
    if HdErrorXYZ(:,3) > 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
else
    if HdErrorXYZ(:,3) < 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
end
if HdErrorXYZ(:,1) > 0  %Error > 0 means Gaze to right of target
    HdXYError = AbHdXYError;  %too far right
else
    HdXYError = -AbHdXYError;  %too far left
end
if HdErrorXYZ(:,3) > 0
    HdZYError = AbHdZYError;  % too high above target
else
    HdZYError = -AbHdZYError;  %too low below target
end

%Format and redefine matrices

clear EL ER EGL EGR SP BGAvg
MT2{k} = [Mt, TGAvg, AbPtrXYError, PtErrorXYZ, PtXYError, PtXYErrorOU, HdErrorXYZ, AbHdXYError, HdXYError, AbHdZYError, HdZYErrorOU, HdEstGz, PtEstGz, TargetOrder];
HDVTR{k} = [Target, BP, HdErrorXYZ, AbHdXYError, HdXYError, AbHdZYError, HdZYErrorOU, HdEstGz, PtEstGz];

%Moving average for determining closest value

X = 1;
if X == 1
    A = 25;
    Average = tsmovavg(MT2{k}(:,41), 's', A, 1);  %'A' point moving average
    [J, ri] = min(Average(:,1));  %Find row index (ri) of minimum value moving average
    MT2{k} = MT2{k}(ri-(A-1):ri,:);  %Select 'A' prior rows from the matrix
H{k} = [ri(1,1)]; %Log the selected row indices
end

MSTDAz{k} = std(MT2{k}(;42));
MSTDEl{k} = std(MT2{k}(;44));

if MSTDAz{k}(1,1) > 0.25
  MTS{k} = [];
  Y=1;
elseif MSTDEl{k}(1,1) > 0.25
  MTS{k} = [];
  Y=1;
else
  MTS{k} = MT2{k};
  Y=0;
end

if Y==0
  MErr{k} = mean(MTS{k}(;,:));
  MStd{k} = std(MTS{k}(;,:));
  MR{k} = range(MTS{k}(;,:));
else
  MErr{k} = [];
  MStd{k} = [];
  MR{k} = [];
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%____________________________________________________________________
MPlot = HDVTR{k};
MPlotT{k} = MPlot;
BPmin2 = min(find(MPlot(:,2)<3));
if min(MPlot(:,2)>3)
  Test = 1
  BPmin2 = length(MPlot(:,2))
end

LTH = length(MPlot(:,1));
MPlotX = (1:LTH)/100;
v=MPlot(1:BPmin2,12);
v = round(v*1000)/1000;
v =smooth(v,11); %v = tsmovavg(v,'s',10, 1);
v1=v;
x = MPlotX(1:BPmin2);
figure(1)
plot(x, v)
delta = 0.035;

% Eli Billauer, 3.4.05 (Explicitly not copyrighted). Modified
% This function is released to the public domain; Any use is allowed.
maxtab = [];
mintab = [];
if nargin < 3
    x = (1:length(v))';
else
    x = x(:);
    if length(v) ~= length(x)
        error('Input vectors v and x must have same length');
    end
end

if (length(delta(:)))>1
    error('Input argument DELTA must be a scalar');
end
if delta <= 0
    error('Input argument DELTA must be positive');
end

mn = Inf; mx = -Inf;
mnpos = NaN; mxpos = NaN;
lookformax = 1;
for i=1:length(v)
    this = v(i);
    if this > mx, mx = this; mxpos = x(i); end
    if this < mn, mn = this; mnpos = x(i); end

    if lookformax
        if this < mx-delta
            maxtab = [maxtab ; mxpos mx];
            mn = this; mnpos = x(i);
            lookformax = 0;
        end
    else
        if this > mn+delta
            mintab = [mintab ; mnpos mn];
            mx = this; mxpos = x(i);
            lookformax = 1;
        end
    end
end

AzMax = [maxtab];
AzMin = [mintab];
AzMaxC = size(AzMin);
AzMinC = size(AzMin);

v=MPlot(1:BPmin2,14);
v = round(v*1000)/1000;
v = smooth(v,11);
x = MPlotX(1:BPmin2);
figure(2)
plot(x,v)
delta = 0.035;

maxtab = [];
mintab = [];
if nargin < 3
    x = (1:length(v))';
else
    x = x(:);
    if length(v)~= length(x)
        error('Input vectors v and x must have same length');
    end
end

if (length(delta(:)))>1
    error('Input argument DELTA must be a scalar');
end

if delta <= 0
    error('Input argument DELTA must be positive');
end

mn = Inf; mx = -Inf;
mnpos = NaN; mXpos = NaN;
lookformax = 1;

for i=1:length(v)
    this = v(i);
    if this > mx, mx = this; mXpos = x(i); end
    if this < mn, mn = this; mNpos = x(i); end

    if lookformax
        if this < mx-delta
            maxtab = [maxtab ; mXpos mx];
            mn = this; mNpos = x(i);
            lookformax = 0;
        end
    else
        if this > mn+delta
            mintab = [mintab ; mNpos mn];
            mx = this; mXpos = x(i);
            lookformax = 1;
        end
    end
end

ElMax = maxtab;
ElMin = mintab;
%ElMaxC = 1;
ElMaxC = size(ElMin);
ElMinC = size(ElMin);
% ElMaxC = length(ElMax);
% ElMinC = length(ElMin);
TransC{k} = [Target(1:1), AzMaxC(1:1), AzMinC(1:1), ElMaxC(1:1), ElMinC(1:1)];

%Test = 2

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Calculate Path Length
v=MPlot(1:BPmin2,6);
BPmin2a{k} = BPmin2;
v2{k} = v;
v = round(v*1000)/1000;
v = smooth(v,11);
v1=v;
x = MPlotX(1:BPmin2);
AzPath = 0;
AzPathAbs = 0;
ElPath = 0;
ElPathAbs = 0;
m=length(v);
m1{k} = m;
% there are m-1 splines for m points
for i=1:1:m-1
dy= v(i+1)-v(i);
AzPathAbs = AzPathAbs + abs(dy);
AzPath = AzPath + dy;
end
AzPath2 = [AzPathAbs,AzPath, MPlotX(BPmin2)];
AzPathAbs2{k} = AzPath;
AzPath3{k} = AzPath2;

v=MPlot(1:BPmin2,8);
v = round(v*1000)/1000;
v = smooth(v,11);
x = MPlotX(1:BPmin2);
m=length(v);
% there are m-1 splines for m points
for i=1:1:m-1
%dx=x(i+1)-x(i);
dy2= v(i+1)-v(i);
ElPath = ElPath + dy2;
ElPathAbs = ElPathAbs + abs(dy2);
end
ElPath2 = [ElPathAbs,ElPath, MPlotX(BPmin2)];

Path{k} = [Target(1:1), AzPath2, ElPath2,TargetOrder(1:1)];

end
clear Tpx Tpy Tpz r L Target I2 I3 Mt ri Time T ScalProj EstMag EstScl I J
ErrorR ErrorL
clear SPL SPR PGAvgL PGAvgR ScalProjL ScalProjR TGAvgL TGAvgR TP EstGL EstGR
Average
clear ErrorMagL ErrorMagR EAvg EGAvg Error ErrorMag EstG EstGz A

%Convert the cell into one Matrix
%M2 = M1';
MF = cell2mat(MTS');
MError = cell2mat(MErr');
MStDev = cell2mat(MStd');
MRg = cell2mat(MR');
HDVTR2 = cell2mat(HDVTR');
Transitions = cell2mat(TransC');
PathLength = cell2mat(Path');
MSSS = [MError(:,23:28),MError(:,32:53)];
MStDev = [MStDev(:,42),MStDev(:,44)];
MRg = [MRg(:,42),MRg(:,44)];
TemporalData = [Transitions, PathLength];

TempDataSave = [myFolder, 'TemporalData.mat'];
save(TempDataSave, 'TemporalData');  % save the matrix
TempDataSave = [myFolder, 'HeadData.mat'];
save(TempDataSave, 'HDVTR2');  % save the matrix

LED Targets – Error

clear
myFolder = '\S_0014b\VtoH1\';
if ~isdir(myFolder)
    errorMessage = sprintf('Error: The following folder does not exist:
%s', myFolder);
    uiwait(warndlg(errorMessage));
    return;
end
filePattern = fullfile(myFolder, 'rwn*.xlsx');
expFiles = dir(filePattern);
for k = 1:length(expFiles)
    i = k;
    baseFileName = expFiles(k).name;
    fullfile = fullfile(myFolder, baseFileName);
    %T = xlsread(fullfile);
    %eval(['M_',int2str(k-1),' = xlsread(fullfile);']);
    M{i} = xlsread(fullfile);
    %I = find(M{i}(:,23)<4);
end
clear baseFileName fullfile expFiles filePattern i k errorMessage
TpFile = xlsread('\LED Targets2.xlsx');
Tp = TpFile(:,1:5);

k=1;
filePattern = fullfile(myFolder, '*order*.xlsx');
expFiles = dir(filePattern);

baseFileName = expFiles(k).name;
fullFile = fullfile(myFolder, baseFileName);
T1 = xlsread(fullfile);  

k=1;  
filePath = fullfile(myFolder, 'Mod.xlsx');  
expFiles = dir(filePath);  

baseFileName = expFiles(k).name;  
fullFileName = fullfile(myFolder, baseFileName);  

HdMod = xlsread(fullfile);  
clear filePath expFiles baseFileName fullFileName k  

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Append for only data during button push and add target data from Target
%list and target position  
%k = 1:length(M)  
for k = 1:length(M);  

%Remove additional columns  
M1{k} = M{k};  
M1{k}(:,2:7) = [];  
M1{k}(:,16:18) = [];  
M1{k}(:,49:52) = [];  

I = find(M1{k}(:,49)<3); % Find times of button push  
if min(I) < 125  
 T = min(I)-1;  
else  
 T = 125;  
end  
I2 = min(I)-T;  
I3 = min(I)+T;  
M1{k} = [M1{k}(I2:I3,:)];  

%Select rows where button is pushed  

%Select Rows prior to and after button push through button push  

%Add target data to the Matrix  
L = length(M1{k}(,:,23));  
\%Length of current matrix  
r = T1(k,4);  
\%Determine xyz position of target from  
position vector  
Target = r * ones(L,1);  
\%Place the target number in the matrix  
Tpx = Tp(r,1)*ones(L,1);  
\%X position of current target  
Tpy = Tp(r,2)*ones(L,1);  
\%Y position of current target  
Tpz = Tp(r,3)*ones(L,1);  
\%Z position of the target  
Row = Tp(r,4)*ones(L,1);  
\%Row of the target  
Column = Tp(r,5)*ones(L,1);  
\%Column of the target  
M1{k} = [M1{k},Target,Tpx,Tpy,Tpz,Row,Column];
Mt = M1{k};
TargetIndex = Tl(k,3);
TargetOrder = TargetIndex*ones(L,1);
HdErrorX = HdMod(1,1)*ones(L,1);
HdErrorY = HdMod(1,2)*ones(L,1);
HdErrorZ = HdMod(1,3)*ones(L,1);

%Manipulate Data

EL = Mt(:, 16:18);   %Left eye position
ER = Mt(:, 19:21);  %Right eye position
EAvg = (EL + ER)/2;  %Calculate the average eye position
TP = Mt(:,57:59);   %Target position XXY coordinates
TGAvg = TP - EAvg;   %Actual Vector from Eye CL to Target
TGAvgR = TP - ER;   %Actual Vector from Rt Eye to Target
TGAvgL = TP - EL;   %Actual Vector from Lt Eye to Target
EGL = Mt(:, 22:24);     %Actual Gaze from left eye
EGR = Mt(:, 25:27);     %Actual Gaze from right eye
EGAvg = [EGAvg(:,1)*1, EGAvg(:,2), EGAvg(:,3)];
BF = Mt(:,28:30);
BGAvg = BF - EAvg;   %Gaze vector from binocular focal point
TGAvgXYM = (TGAvg(:,1).*TGAvg(:,2).*TGAvg(:,2)).^0.5; %XYMag of target vector
TGAvgZYM = (TGAvg(:,3).*TGAvg(:,2).*TGAvg(:,2)).^0.5; %ZYMag of target vector
AbXYError = radtodeg(acos(((TGAvg(:,1).*EGAvg(:,1))+(TGAvg(:,2).*EGAvg(:,2)))./(TGAvgXYM.*EGAvgXYM))); %XY angle error
AbZYError = radtodeg(acos(((TGAvg(:,3).*EGAvg(:,3))+(TGAvg(:,2).*EGAvg(:,2)))./(TGAvgZYM.*EGAvgZYM))); %ZY angle error

%Calculate the point on gaze vector where the error is minimum (calculate %the orthogonal projection from the gaze vector)
ScalProj = dot(TGAvg,EGAvg,2); % Returns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
P Avg = EGAvg.*SP; %Scaled Gaze Vector
EstGPt = EAvg + P Avg; %XYZ coordinates of point along gaze vector with minimum error
ErrorXYZ = (TP - EstGPt)*100; %Error to the actual target position
ErrorMag = sqrt(sum((ErrorXYZ'.^2))'); %Magnitude of error

% Pointer Data

PtrAV = Mt(:,13:15)-Mt(:,10:12);
PtrAVMag = sqrt(sum((PtrAV'.^2))');
ptrAV = PtrAV ./ [PtrAVMag,PtrAVMag,PtrAVMag];
PtrTV = TP - Mt(:,10:12);
PtrTVAvgXYM = (PtrTV(:,1).*PtrTV(:,2).*PtrTV(:,2)).^0.5; %XYMag of pointer to target pointer vector
PtrTVAvgZYM = (PtrTV(:,3).*PtrTV(:,2).*PtrTV(:,2)).^0.5; %ZYMag of actual pointer vector
AbPtrXYError =
radtodeg(acos(((PtrTV(:,1).*PtrAV(:,1))+(PtrTV(:,2).*PtrAV(:,2)))./(PtrTVAvgXYM.*PtrAVAvgXYM)));
ScalProj = dot(PtrTV,ptrAV,2); % Resturns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
PtPGAvg = ptrAV.*SP; %Scaled Pointer Vector
PtEstGPt = Mt(:,10:12) + PtPGAvg; %XYZ coordinates of point along pointer vector with minimum error
PtErrorXYZ = (TP - PtEstGPt)*100; %Error to the actual target position
PtErrorMag = sqrt(sum((PtErrorXYZ'.^2)));
PtEstMag = 1.136 - Mt(:,11); % Distance from Board Plane to head
PtEstScl = PtEstMag ./ ptrAV(:,2); %Scaler to have Y head vector intersect plane
PtEstGz = ptrAV.*[PtEstScl,PtEstScl,PtEstScl] + Mt(:,10:12);

%Head Vector

HdError = [HdErrorX,HdErrorY,HdErrorZ];
HdAVa = Mt(:,4:6)-Mt(:,7:9);
HdAVMag = sqrt(sum((HdAVa'.^2)));
HdAVMag2 = HdAVMag / 2;
hdAV = HdAVa ./ [HdAVMag,HdAVMag,HdAVMag];
HdNPos = HdOPos + HdError;
HdAV = Mt(:,4:6)-HdNPos;
HdAVMag = sqrt(sum((HdAVa'.^2)));
HdAVMag2 = HdAVMag / 2;
hdAV = HdAV ./ [HdAVMag,HdAVMag,HdAVMag];
HdTV = TP - HdNPos;
HdTVAvgXYM = (HdTV(:,1).^2+HdTV(:,2).^2).^0.5; %XYMag of head to target pointer vector
HdAVAvgXYM = (HdAV(:,1).^2+HdAV(:,2).^2).^0.5; %XYMag of actual pointer vector
AbHdXYError =
radtodeg(acos(((HdTV(:,1).*HdAV(:,1))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgXYM.*HdAVAvgXYM)));
HdTVAvgZYM = (HdTV(:,3).^2+HdTV(:,2).^2).^0.5; %ZYMag of Head vector
HdAVAvgZYM = (HdAV(:,3).^2+HdAV(:,2).^2).^0.5; %ZYMag of head vector
AbHdZYError =
radtodeg(acos(((HdTV(:,3).*HdAV(:,3))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgZYM.*HdAVAvgZYM)));
ScalProj = dot(HdTV,hdAV,2); % Resturns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
HdPGAvg = hdAV.*SP; %Scaled Pointer Vector
HdEstGPt = HdNPos + HdPGAvg; %XYZ coordinates of point along pointer vector with minimum error
HdErrorXYZ = (TP - HdEstGPt)*100; %Error to the actual target position
HdErrorMag = sqrt(sum((HdErrorXYZ'.^2)));
HdEstMag = .99 - HdNPos(:,2); % Distance from Board Plane to head
HdEstScl = HdEstMag ./ hdAV(:,2); %Scaler to have Y head vector intersect plane
HdEstGz = hdAV.*[HdEstScl,HdEstScl,HdEstScl] + HdNPos;
Check = [HdEstGz];
%Direction of Error: Underestimation is negative
if TGAvg > 0
    if ErrorXYZ(:,1) > 0
        XYErrorOU = -AbXYError;
    else
        XYErrorOU = AbXYError;
    end
else
    if ErrorXYZ(:,1) < 0
        XYErrorOU = -AbXYError;
    else
        XYErrorOU = AbXYError;
    end
end
if TGAvg > 0
    if ErrorXYZ(:,3) > 0
        ZYErrorOU = -AbZYError;
    else
        ZYErrorOU = AbZYError;
    end
else
    if ErrorXYZ(:,3) < 0
        ZYErrorOU = -AbZYError;
    else
        ZYErrorOU = AbZYError;
    end
end
if ErrorXYZ(:,1) > 0
    XYError = +AbXYError;
else
    XYError = -AbXYError;
end
if ErrorXYZ(:,3) > 0
    ZYError = AbZYError;
else
    ZYError = -AbZYError;
end
%for the pointer
if TGAvg > 0
    if PtErrorXYZ(:,1) > 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
else
    if PtErrorXYZ(:,1) < 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
end
if PtErrorXYZ(:,1) > 0
    PtXYError = AbPtrXYError;
else

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PtXYError = -AbPtrXYError;

% for the head
if TGAvg > 0
    if HdErrorXYZ(:,1) > 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
else
    if HdErrorXYZ(:,1) < 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
end
if TGAvg > 0
    if HdErrorXYZ(:,3) > 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
else
    if HdErrorXYZ(:,3) < 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
end
if HdErrorXYZ(:,1) > 0
    HdXYError = AbHdXYError;
else
    HdXYError = -AbHdXYError;
end
if HdErrorXYZ(:,3) > 0
    HdZYError = AbHdZYError;
else
    HdZYError = -AbHdZYError;
end

% Error from individual eyes
% Right
  ScalProjR = dot(TGAvgR,EGR,2); % Returns the scaler projection magnitude for minimum error
  SPR = [ScalProjR,ScalProjR,ScalProjR]; % Matrix formatting for multiplication
  PGAvgR = EGR.*SP; % Scaled Gaze Vector
  EstGR = ER + PGAvgR; % XYZ coordinates of point along gaze vector with minimum error
  ErrorR = (TP - EstGR)*100; % Error to the actual target position
  ErrorMagR = sqrt(sum((ErrorR'.^2))'); % Magnitude of error

% Left
ScalProjL = dot(TGAvgL, EGL, 2); % Returns the scaler projection magnitude for minimum error
SPL = [ScalProjL, ScalProjL, ScalProjL]; % Matrix formatting for multiplication
PGAvgL = EGL.*SP; % Scaled Gaze Vector
EstGL = EL + PGAvgL; % XYZ coordinates of point along gaze vector with minimum error
ErrorL = (TP - EstGL)*100; % Error to the actual target position
ErrorMagL = sqrt(sum((ErrorL'.^2))'); % Magnitude of error

% Calculate the X and Z positions at the point where the gaze vector crosses the plane (assuming Y = 0.99)
EstMag = .99 - EAvg(:,2); % Distance from Avg Eye Pos to board plane
EstSc1 = EstMag ./ EGAvg(:,2); % Scaler to have Y Gze vector intersect plane
EstGz = EGAvg.*[EstSc1, EstSc1, EstSc1] + EAvg; % Point where crosses Y plane

% Format and redefine matrices

clear EL ER EGL EGR SP BGAvg
MT2{k} = [Mt, TGAvg, EGAvg, PGAvg, ScalProj, EstGpt, ErrorXYZ, ErrorMag, AbXYError, XYError, XErrorOU, AbZYError, ZError, ZErrorOU, AbPtrXYError, EstGz, ErrorR, ErrorL, PtErrorXYZ, PtXYError, PtXError, HdErrorXYZ, AbHdXYError, HdXYError, AbHdZYError, HdZYError, HdXYErrorOU, HdZYErrorOU, HdEstGz, PtEstGz, TargetOrder];

% Moving average for determining closest value

X = 1;
if X == 1
A = 25;
Average = tsmovavg(MT2{k}(:,78),'s',A, 1); % 'A' point moving average
[J,ri] = min(Average(:,1)); % Find row index (ri) of minimum value moving average
MT2{k} = MT2{k}(ri-(A-1):ri,:); % Select 'A' prior rows from the matrix
H{k} = [ri(1,1)]; % Log the selected row indices
end
MSTDAz{k} = std(MT2{k}(:,79));
MSTDEl{k} = std(MT2{k}(:,81));

if MSTDAz{k}(1,1) > 0.25
MTS{k} = [];
Y=1;
elseif MSTDEl{k}(1,1) > 0.25
MTS{k} = [];
Y=1;
else
MTS{k} = MT2{k};
Y=0;
end

if Y==0
MErr{k} = mean(MTS{k}(:,:));
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MStd{k} = std(MTS{k}(:, :));
MR{k} = range(MTS{k}(:, :));
else
  MErr{k} = [];
  MStd{k} = [];
  MR{k} = [];
end

end
clear Tpx Tpy Tpz r L k Target I2 I3 Mt ri Time T ScalProj EstMag EstScl I J ErrorR ErrorL
clear SPL SPR PGAvgL PGAvgR ScalProjL ScalProjR TGAvgL TGAvgR TP EstGL EstGR Average
clear ErrorMagL ErrorMagR EAvg EG Avg Error ErrorMag EstG EstGz A

% Convert the cell into one Matrix
MF = cell2mat(MTS');
MError = cell2mat(MErr');
MStDev = cell2mat(MStd');
MRg = cell2mat(MR');
MeanErr = mean(MError(:,75:82))
StdErr = std(MError(:,75:82))
MSPSS = [MError(:,56:61),MError(:,72:88),MError(:,95:115)];

LED Targets – Spatial Plots

clear
myFolder = '\VtoH1\'; % Set Path of LED files
if ~isdir(myFolder)
  errorMessage = sprintf('Error: The following folder does not exist:
%s',
    myFolder);
  uiwait(warndlg(errorMessage));
  return;
end
filePattern = fullfile(myFolder, 'rwn*.xlsx');
expFiles = dir(filePattern);
for k = 1:length(expFiles)
  i = k;
  baseFileName = expFiles(k).name;
  fullFileName = fullfile(myFolder, baseFileName);
  %T = xlsread(fullfileName);
  %eval(['M_','int2str(k-1),' = xlsread(fullfileName);'])
  M{i} = xlsread(fullfileName);
  %I = find(M{1}(:,23)<4);  
end
clear baseFileName fullfile expFiles filePattern i k errorMessage

% Target Matrix
TpFile = xlsread('\LED Targets2.xlsx'); % Set Path of targets
Tp = TpFile(:,1:5);

k = 1;
filePattern = fullfile(myFolder, '*order*.xlsx');
expFiles = dir(filePattern);

baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);
Tl = xlsread(fullFileName);
clear filePattern expFiles baseFileName fullFileName k

% Append for only data during button push and add target data from Target
% list and target position
% k = 1:length(M)
for k = 1:length(M);
    Tl = [1 2 3 4 5 6 7 8 9 1 2 1];
    Tp = [1 2 3; 1 2 3; 1 2 3; 1 2 3; 1 2 3; 1 2 3; 1 2 3; 1 2 3; 1 2 3];
    I = find(M{k}(:,62)<3); % Find times of button push
    Temporal = 1
    if Temporal == 0
        if min(I) < 125
            T = min(I)-1;
        else
            T = 125;
        end
        I2 = min(I)-T;
        I3 = min(I)+125;
        % Select Rows prior to and after button push through button push
        M1{k} = [M{k}(I2:I3,:);]
    else
        T = 1000;
        M1{k} = [M{k}(:,,:);]
    end
    % if min(I) < 300
    %     T = min(I)-1;
    % else
    %     T = 300;
    % end

    % Add target data to the Matrix
    L = length(M1{k}(:,23)); % Length of current matrix
    r = Tl(k,4); % Determine xyz position of target from position vector
    Target = r * ones(L,1); % Place the target number in the matrix
    Tpx = Tp(r,1)*ones(L,1); % X position of current target
    Tpy = Tp(r,2)*ones(L,1); % Y position of current target
    Tpz = Tp(r,3)*ones(L,1); % Z position of current target
    Row = Tp(r,4)*ones(L,1); % Row of the target
    Column = Tp(r,5)*ones(L,1); % Column of the target
    Trial = 1*ones(L,1);
    % Time = M1{k}(,1)*4;
M1{k} = [M1{k}, Target, Tpx, Tpy, Tpz, Row, Column, Trial];
Mt = M1{k};

%Mmanipulate Data
MErr{k} = mean(M1{k}(:,:));
MTS{k} = M1{k};
end

clear Tpx Tpy Tpz r L k Target I2 I3 Mt ri Time ScalProj EstMag EstScl I J
ErrorR ErrorL

clear SPL SPR PGAvgL PGAvgR ScalProjL ScalProjR TGAvgL TGAvgR TP EstGL EstGR
Average

clear ErrorMagL ErrorMagR EAvg EGAvg Error ErrorMag EstG EstGz A

%Convert the cell into one Matrix

%M2 = M1';
MF = cell2mat(MTS');
MError = cell2mat(MErr');
Bias = mean(MError(:,58:61));
MF2 = [MF, MF(:,58)-1, MF(:,59)-(4), MF(:,60)-(-.35), MF(:,61)-5.2];
MError2 = [MError, MError(:,58)-1, MError(:,59)-(4), MError(:,60)-(-.35), MError(:,61)-5.2];

SDev = std(MError2(:,76:79));
%MSPSS = [MError(:,56:61), MError(:,72:88), MError(:,95:114)];

%Plot Data
if Temporal ==1
SV = 1;
figure(1)
TL = 1:9;
if SV==1
h = figure;
end
for k = TL;
MPlot = MF2(MF2(:,69)==k,:); %C69 is Target Number
LTH = length(Mplot(:,1));
MPlotX = MPlot(:,1)*4;
plot(MPlotX, MPlot(:,76),'-'); %C58 is Horizontal Eye Angle
hold on
end
plot(T,-30:30,'-k')
ifplot(T,0,'o','MarkerEdgeColor','k','MarkerFaceColor','k','MarkerSize',10)
hold off
xlabel('Time (ms)')
ylabel('Eye Angle')
title('Left Eye, Horizontal')
axis([0 4000 -30 30])
if SV==1
LHFP = [myFolder,'LH.fig']
saveas(h, LHFP)  % here you save the figure
end

%______________________________________
figure(2)
if SV==1
h = figure;
end
for k = TL;
    MPlot = MF2(MF2(:,69)==k,:); %C69 is Target Number
    MPotX = MPlot(:,1)*4;
    plot(MPotX, MPlot(:,77),'-');      %C58 is Horizontal Eye Angle
    hold on
end
plot(T,-30:30,'-k')
hold off
xlabel('Time')
ylabel('Eye Angle')
title('Left Eye, Vertical')
axis([0 4000 -30 30])
if SV == 1;
    LVFP = [myFolder,'LV.fig']
saveas(h, LVFP)  % here you save the figure
end
%______________________________________
figure(3)
if SV==1
h = figure;
end
for k = TL;
    MPlot = MF2(MF2(:,69)==k,:); %C69 is Target Number
    MPotX = MPlot(:,1)*4;
    plot(MPotX, MPlot(:,78),'-');      %C58 is Horizontal Eye Angle
    hold on
end
plot(T,-30:30,'-k')
hold off
xlabel('Time')
ylabel('Eye Angle')
title('Right Eye, Horizontal')
axis([0 4000 -30 30])
if SV == 1;
    RHFP = [myFolder,'RH.fig']
saveas(h, RHFP)  % here you save the figure
end
%______________________________________
figure(4)
if SV==1
h = figure;
end
for k = TL;
    MPlot = MF2(MF2(:,69)==k,:); %C69 is Target Number
    MPotX = MPlot(:,1)*4;
    plot(MPotX, MPlot(:,79),'-');      %C58 is Horizontal Eye Angle
Correction Vector – Sighted

clear
myFolder = '\S_0014b\Audio\';
if ~isdir(myFolder)
    errorMessage = sprintf('Error: The following folder does not exist:
%s', myFolder);
    uiwait(warndlg(errorMessage));
    return;
end
filePattern = fullfile(myFolder, 'rwn*.xlsx');
expFiles = dir(filePattern);
for k = 1:length(expFiles)
    i = k;
    baseFileName = expFiles(k).name;
    fullFileName = fullfile(myFolder, baseFileName);
    M{i} = xlsread(fullFileName);
end
clear baseFileName fullFileName expFiles filePattern i k errorMessage

% Target Matrix
TpFile = xlsread('\91 Audio Targets.xlsx');
Tp = TpFile(:,1:5);
k=1;
filePattern = fullfile(myFolder, '*order*.xlsx');
expFiles = dir(filePattern);

baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);
T1 = xlsread(fullFileName);
clear filePattern expFiles baseFileName fullFileName k

%Append for only data during button push and add target data from Target %list and target position
for k = 1:length(M);

%Remove additional columns
M1{k} = M{k};
M1{k}(:,2:7) = [];
M1{k}(:,16:18) = [];
M1{k}(:,49:52) = [];
MTest{k} = M1{k};
I = find(M1{k}(:,49)<3); % Find times of button push
if min(I) < 125
  T = min(I)-1;
else
  T = 125;
end
I2 = min(I)-T;
I3 = min(I)+T;

%Select Rows where button is pushed
%Select Rows prior to and after button push through button push
M1{k} = [M1{k}(I2:I3,:)];

%Add target data to the Matrix
L = length(M1{k}(:,23)); %Length of current matrix
r = Tl(k,4); %Determine xyz position of target from position vector
Target = r * ones(L,1); %Place the target number in the matrix
Tpx = Tp(r,1)*ones(L,1); %X position of current target
Tpy = Tp(r,2)*ones(L,1); %Y position of current target
Tpz = Tp(r,3)*ones(L,1); %Z position of current target
Row = Tp(r,4)*ones(L,1); %Row of the target
Column = Tp(r,5)*ones(L,1); %Column of the target
M1{k} = [M1{k},Target,Tpx,Tpy,Tpz,Row,Column];
Mt = M1{k};
TargetIndex = Tl(k,3);
TargetOrder = TargetIndex*ones(L,1);

%Manipulate Data
EL = Mt(:,16:18); %Left eye position
ER = Mt(:,19:21); %Right eye position
EAvg = (EL + ER)/2; %Calculate the average eye position
TP = Mt(:,57:59); %Target position XYX coordinates
TGAvg = TP - EAvg; %Actual Vector from Eye CL to Target
TGAvgR = TP - ER; %Actual Vector from Rt Eye to Target
TGAvgL = TP - EL; %Actual Vector from Lt Eye to Target
EGL = Mt(:,22:24); %Actual Gaze from left eye
EGR = Mt(:,25:27); %Actual Gaze from right eye
EGAvg = (EGL + EGR)/2; %Average binocular gaze
EGAvg = [EAvg(:,1)*1, EGAvg(:,2), EGAvg(:,3)];
BF = Mt(:,28:30);
BGAvg = BF - EAvg; %Gaze vector from binocular focal point
TGAvgXYM = (TGAvg(:,1).^2+TGAvg(:,2).^2).^0.5; %XYMag of target vector
EGAvgXYM = (EGAvg(:,1).^2+EGAvg(:,2).^2).^0.5; %XYMag of gaze vector

AbXYError =
radtodeg(acos(((TGAvg(:,1).*EGAvg(:,1))+(TGAvg(:,2).*EGAvg(:,2)))./(TGAvgXYM.*EGAvgXYM))));  %XY angle error

TGAvgZYM = (TGAvg(:,3).^2+TGAvg(:,2).^2).^0.5; %ZYMag of gaze vector
EGAvgZYM = (EGAvg(:,3).^2+EGAvg(:,2).^2).^0.5; %ZYMag of gaze vector

AbZYError =
radtodeg(acos(((TGAvg(:,3).*EGAvg(:,3))+(TGAvg(:,2).*EGAvg(:,2)))./(TGAvgZYM.*EGAvgZYM))));  %ZY angle error

% Calculate the point on gaze vector where the error is minimum (calculate
% the orthogonal projection from the gaze vector)
ScalProj = dot(TGAvg,EGAvg,2); % Returns the scaler projection magnitude for
minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
PGAvg = EGAvg.*SP; %Scaled Gaze Vector

EstGPt = EAvg + PGAvg; %XYZ coordinates of point along gaze vector with
minimum error

ErrorXYZ = (TP - EstGPt)*100; %Error to the actual target position
ErrorMag = sqrt(sum((ErrorXYZ'.^2))); %Magnitude of error

% Pointer Data

PtrAV = Mt(:,13:15)-Mt(:,10:12);
PtrAVMag = sqrt(sum((PtrAV'.^2))');

ptrAV = PtrAV ./ [PtrAVMag,PtrAVMag,PtrAVMag];

PtrTV = TP - Mt(:,10:12);
PtrTVAvgXYM = (PtrTV(:,1).^2+PtrTV(:,2).^2).^0.5; %XYMag of pointer to target
pointer vector

PtrAVAvgXYM = (PtrAV(:,1).^2+PtrAV(:,2).^2).^0.5; %XYMag of actual pointer
vector

AbPtrXYError =
radtodeg(acos(((PtrTV(:,1).*PtrAV(:,1))+(PtrTV(:,2).*PtrAV(:,2)))./(PtrTVAvgXYM.*PtrAVAvgXYM)));

ScalProj = dot(PtrTV,ptrAV,2); % Resturns the scaler projection magnitude for
minimum error

SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
PtPGAvg = ptrAV.*SP; %Scaled Pointer Vector

PtEstGPt = Mt(:,10:12) + PtPGAvg; %XYZ coordinates of point along pointer
vector with minimum error

PtErrorXYZ = (TP - PtEstGPt)*100; %Error to the actual target position
PtErrorMag = sqrt(sum((PtErrorXYZ'.^2))');

PtEstMag = 1.136 - Mt(:,11); % Distance from Board Plane to head

PtEstScl = PtEstMag ./ ptrAV(:,2); %Scaler to have Y head vector intersect
plane

PtEstGz =ptrAV.*[PtEstScl,PtEstScl,PtEstScl] + Mt(:,10:12);

% Head Vector

HdAVa = Mt(:,4:6)-Mt(:,7:9);
HdAVMag = sqrt(sum((HdAVa'.^2))');
hdAV = HdAVa ./ [HdAVMag,HdAVMag,HdAVMag]; % Normalized head vector
\[HdTV = TP - Mt(:,4:6);\]
\[HdTVMag = \sqrt{\text{sum}((HdTV'.^2))'};\]
\[hdTV = HdTV ./ [HdTVMag,HdTVMag,HdTVMag]; \% Normalized head to target vector\]
\[HdAdjScalY = HdAVMag/2;\]
\[HdEstAdjGz = Mt(:,4:6) - hdTV.*[HdAdjScalY,HdAdjScalY,HdAdjScalY]; \% Position in head with target vector\]
\[HdEstAdjGzO = Mt(:,4:6) - hdAV.*[HdAdjScalY,HdAdjScalY,HdAdjScalY]; \% Position in head with original vector\]
\[HdEstAdjGzT = [HdEstAdjGz, HdEstAdjGzO, HdEstAdjGz - HdEstAdjGzO];\]

\[HdAV = Mt(:,4:6)-Mt(:,7:9);\]
\[HdAVMag = \sqrt{\text{sum}((HdAV'.^2))'};\]
\[hdAV = HdAV ./ [HdAVMag,HdAVMag,HdAVMag];\]
\[HdTV = TP - Mt(:,4:6);\]
\[HdTVAvgXYM = (HdTV(:,1).^2+HdTV(:,2).^2).^0.5; \% XYMag of head to target pointer vector\]
\[HdAVAvgXYM = (HdAV(:,1).^2+HdAV(:,2).^2).^0.5; \% XYMag of actual pointer vector\]
\[AbdHdXYError = \text{radtodeg}(\text{acos}(((HdTV(:,1).*HdAV(:,1))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgXYM.*HdAVAvgXYM)));\]
\[HdTVAvgZYM = (HdTV(:,3).^2+HdTV(:,2).^2).^0.5; \% ZYMag of head vector\]
\[HdAVAvgZYM = (HdAV(:,3).^2+HdAV(:,2).^2).^0.5; \% ZYMag of head vector\]
\[AbdHdZError = \text{radtodeg}(\text{acos}(((HdTV(:,3).*HdAV(:,3))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgZYM.*HdAVAvgZYM))); \% ZY angle error\]
\[ScalProj = \text{dot}(HdTV,hdAV,2); \% Resturns the scaler projection magnitude for minimum error\]
\[SP = [ScalProj,ScalProj,ScalProj]; \% Matrix formatting for multiplication\]
\[HdPGAvg = hdAV.*SP; \% Scaled Pointer Vector\]
\[HdEstGpT = Mt(:,4:6) + HdPGAvg; \% XYZ coordinates of point along pointer vector with minimum error\]
\[HdErrorXYZ = (TP - HdEstGpT)*100; \% Error to the actual target position\]
\[HdErrorMag = \sqrt{\text{sum}((HdErrorXYZ'.^2))'};\]
\[HdEstMag = 1.136 - Mt(:,5); \% Distance from Board Plane to head\]
\[HdEstScl = HdEstMag ./ hdAV(:,2); \% Scaler to have Y head vector intersect plane\]
\[HdEstGz = hdAV.*[HdEstScl,HdEstScl,HdEstScl] + Mt(:,4:6);\]

\% Direction of Error: Underestimation is negative
if TGAvg > 0
  if ErrorXYZ(:,1) > 0
    XyErrorOU = -AbXYError;
  else
    XyErrorOU = AbXYError;
  end
else
  if ErrorXYZ(:,1) < 0
    XyErrorOU = -AbXYError;
  end
else
    XYErrorOU = AbXYError;
end
end
if TGAvg > 0
    if ErrorXYZ(:,3) > 0
        ZYErrorOU = -AbZYError;
    else
        ZYErrorOU = AbZYError;
    end
else
    if ErrorXYZ(:,3) < 0
        ZYErrorOU = -AbZYError;
    else
        ZYErrorOU = AbZYError;
    end
end
if ErrorXYZ(:,1) > 0
    XYError = +AbXYError;
else
    XYError = -AbXYError;
end
if ErrorXYZ(:,3) > 0
    ZYError = AbZYError;
else
    ZYError = -AbZYError;
end
% for the pointer
if TGAvg > 0
    if PtErrorXYZ(:,1) > 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
else
    if PtErrorXYZ(:,1) < 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
end
if PtErrorXYZ(:,1) > 0
    PtXYError = AbPtrXYError;
else
    PtXYError = -AbPtrXYError;
end
% for the head
if TGAvg > 0
    if HdErrorXYZ(:,1) > 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
end
end
else
  if HdErrorXYZ(:,1) < 0
    HdXYErrorOU = -AbHdXYError;
  else
    HdXYErrorOU = AbHdXYError;
  end
end

if TGAvg > 0
  if HdErrorXYZ(:,3) > 0
    HdZYErrorOU = -AbHdZYError;
  else
    HdZYErrorOU = AbHdZYError;
  end
else
  if HdErrorXYZ(:,3) < 0
    HdZYErrorOU = -AbHdZYError;
  else
    HdZYErrorOU = AbHdZYError;
  end
end

if HdErrorXYZ(:,1) > 0
  HdXYError = AbHdXYError;
else
  HdXYError = -AbHdXYError;
end
if HdErrorXYZ(:,3) > 0
  HdZYError = AbHdZYError;
else
  HdZYError = -AbHdZYError;
end

% Error from individual eyes
% Right
  ScalProjR = dot(TGAvgR,EGR,2); % Returns the scalar projection magnitude
  for minimum error
    SPR = [ScalProjR,ScalProjR,ScalProjR]; % Matrix formatting for
    multiplication
    PGAvgR = EGR.*SP; % Scaled Gaze Vector
    EstGR = ER + PGAvgR; % XYZ coordinates of point along gaze vector with
    minimum error
    ErrorR = (TP - EstGR)*100; % Error to the actual target position
    ErrorMagR = sqrt(sum((ErrorR'.^2))'); % Magnitude of error

% Left
  ScalProjL = dot(TGAvgL,EGL,2); % Returns the scalar projection magnitude
  for minimum error
    SPL = [ScalProjL,ScalProjL,ScalProjL]; % Matrix formatting for
    multiplication
    PGAvgL = EGL.*SP; % Scaled Gaze Vector
    EstGL = EL + PGAvgL; % XYZ coordinates of point along gaze vector with
    minimum error
    ErrorL = (TP - EstGL)*100; % Error to the actual target position
    ErrorMagL = sqrt(sum((ErrorL'.^2))'); % Magnitude of error
%Calculate the X and Z positions at the point where the gaze vector crosses
%the plane (assuming Y = 0.99)

EstMag = 1.136 - EAvg(:,2); % Distance from Avg Eye Pos to board plane
EstScl = EstMag ./ EGAvg(:,2); %Scaler to have Y Gze vector intersect plane
EstGz = EGAvg.*[EstScl,EstScl,EstScl] + EAvg; %Point where crosses Y plane

%Format and redefine matrices

clear EL ER EGL EGR SP BGAvg
MT2{k} = [Mt, TGAvg, EGAvg, PGAvg, ScalProj, EstGpt, ErrorXYZ, ErrorMag, AbXYError, XYError, XYErrorO, AbZYError, ZYError, ZYErrorO, AbPtrXYError, EstGz, ErrorR, ErrorL, PtErrorXYZ, PtXYError, PtXYErrorO, HdErrorXYZ, AbHdXYError, HdXYError, AbHdZYError, HdZYError, HdZYErrorO, HdZYErrorO, HdEstGz, PtEstGz, TargetOrder];

%Moving average for determining closest value

X = 1;
if X == 1

A = 25;
Average = tsmovavg(MT2{k}(:,78), 's', A, 1); %'A' point moving average
[J,ri] = min(Average(:,1)); %Find row index (ri) of minimum value moving average
MT2{k} = MT2{k}(ri-(A-1):ri,:); %Select 'A' prior rows from the matrix
H{k} = [ri(1,1)]; %Log the selected row indices
RotPoint{k} = HdEstAdjGzT(ri-(A-1):ri,:);
end
MSTDAz{k} = std(MT2{k}(:,79));
MSTDEl{k} = std(MT2{k}(:,81));
if MSTDAz{k}(1,1) > 0.25
 MTS{k} = [];
 Y=1;
elseif MSTDEl{k}(1,1) > 0.25
 MTS{k} = [];
 Y=1;
else
 MTS{k} = MT2{k};
 Y=0;
end

if Y==0
 MErr{k} = mean(MTS{k}(:,::));
 MStd{k} = std(MTS{k}(:,::));
 MR{k} = range(MTS{k}(:,::));
else
 MErr{k} = [];
 MStd{k} = [];
 MR{k} = [];
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Determine correection vector called HdError
if Y==0 & & MTS{k}(1,60)==5 %Isolate the center Row
RotationPointElv{k} = RotPoint{k};
RotationPointElv{k} = [RotationPointElv{k}, MTS{k}(:,56)]; % Column 56 is target number
else
    RotationPointElv{k} = [];
end

if Y == 0 && MTS{k}(1,61)==8 % Isolate the center column
    RotationPointAz{k} = RotPoint{k};
    RotationPointAz{k} = [RotationPointAz{k}, MTS{k}(:,56)]; % Column 56 is target number
else
    RotationPointAz{k} = [];
end

clear Tpx Tpy Tpz r L k Target I2 I3 Mt ri Time T ScalProj EstMag EstScl I J ErrorR ErrorL
clear SPL SPR PGAvgL PGAvgR ScalProjL ScalProjR TGAvgL TGAvgR TP EstGL EstGR Average
clear ErrorMagL ErrorMagR EAvg EGAvg Error ErrorMag EstG EstGz A

%Convert the cell into one Matrix
%M2 = M1';
MF = cell2mat(MTS');
MError = cell2mat(MErr');
MStDev = cell2mat(MStd');
MRg = cell2mat(MR');

MRotPointEl = cell2mat(RotationPointElv');
MRotPointAz = cell2mat(RotationPointAz');
MRotZ = mean([MRotPointEl(:,3),MRotPointEl(:,6),MRotPointEl(:,9)]);
MRotX = mean([MRotPointAz(:,1),MRotPointAz(:,4),MRotPointAz(:,7)]);
MRotYAz = mean([MRotPointAz(:,2),MRotPointAz(:,5),MRotPointAz(:,8)]);
MRotYE1 = mean([MRotPointEl(:,2),MRotPointEl(:,5),MRotPointEl(:,8)]);
MRotY = (MRotYAz + MRotYE1)/2;
HdErrorRg = [max(MRotPointAz(:,7))-min(MRotPointAz(:,7)),
              max(MRotPointEl(:,9))-min(MRotPointEl(:,9))];
HdError = [MRotX(:,3),MRotY(:,3),MRotZ(:,3),HdErrorRg];

MeanErr = mean(MError(:,75:82))
StdErr = std(MError(:,75:82))
MSPSS = [MError(:,56:61),MError(:,72:88),MError(:,95:115)];

**Correction Vector – Not Sighted**
clear
myFolder = '\Audio\';
if ~isdir(myFolder)
    errorMessage = sprintf('Error: The following folder does not exist:
%s', myFolder);
    uiwait(warndlg(errorMessage));
    return;
end
filePattern = fullfile(myFolder, 'rwn*.xlsx');
expFiles = dir(filePattern);

for k = 1:length(expFiles)
    i = k;
    baseFileName = expFiles(k).name;
    fullFileName = fullfile(myFolder, baseFileName);
    M{i} = xlsread(fullFileName);
end

clear baseFileName fullFileName expFiles filePattern i k errorMessage

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Target Matrix

TpFile = xlsread('\91 Audio Targets.xlsx');
Tp = TpFile(:,1:5);
k=1;
filePattern = fullfile(myFolder, '*order*.xlsx');
expFiles = dir(filePattern);

baseFileName = expFiles(k).name;
fullFileName = fullfile(myFolder, baseFileName);
Tl = xlsread(fullFileName);

clear filePattern expFiles baseFileName fullFileName k
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Append for only data during button push and add target data from Target
%list and target position

for k = 1:length(M);

%Remove additional columns
M1{k} = M{k};
M1{k}(:,2:7) = [];
M1{k}(:,16:18)=[];

% Find time of button push
%Aligned with MM sample rate of 100 Hz
I = find(M1{k}(:,16)<3); % Find times of button push
if min(I) < 50
    T = min(I)-1;
else
    T = 50; % 30 seconds on either side of button push
end
I2 = min(I) - T;
I3 = min(I) + T;
% Select Rows prior to and after button push through button push
M1{k} = [M1{k}(I2:I3,:)];

% Add target data to the Matrix
L = length(M1{k}(:,22)); % Length of current matrix
r = Tl(k,4); % Determine xyz position of target from position vector
Target = r * ones(L,1); % Place the target number in the matrix
Tpx = Tp(r,1)*ones(L,1); % X position of current target
Tpy = Tp(r,2)*ones(L,1); % Y position of current target
Tpz = Tp(r,3)*ones(L,1); % Z position of current target
Row = Tp(r,4)*ones(L,1); % Row of the target
Column = Tp(r,5)*ones(L,1); % Column of the target
M1{k} = [M1{k},Target,Tpx,Tpy,Tpz,Row,Column];
Mt = M1{k};
TargetIndex = Tl(k,3);
TargetOrder = TargetIndex*ones(L,1);

% Manipulate Data
TP = Mt(:,24:26); % Target position XYX coordinates
TGAvg = TP - Mt(:,4:6); % Actual Vector from Eye CL to Target

% Pointer Data
PtrAV = Mt(:,13:15)-Mt(:,10:12);
PtrAVMag = sqrt(sum((PtrAV'.^2))');
ptrAV = PtrAV ./ [PtrAVMag,PtrAVMag,PtrAVMag];
PtrTV = TP - Mt(:,10:12);
PtrTVAvgXYM = (PtrTV(:,1).^2+PtrTV(:,2).^2).^0.5; % XYM of pointer to target pointer vector
PtrAVAvgXYM = (PtrAV(:,1).^2+PtrAV(:,2).^2).^0.5; % XYM of actual pointer vector
AbPtrXYError = radtodeg(acos(((PtrTV(:,1).*PtrAV(:,1))+(PtrTV(:,2).*PtrAV(:,2)))./(PtrTVAvgXYM.*PtrAVAvgXYM)));
ScalProj = dot(PtrTV,ptrAV,2); % Returns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; % Matrix formatting for multiplication
PtPGAv = ptrAV.*SP; % Scaled Pointer Vector
PtEstGpt = Mt(:,10:12) + PtPGAv; % XYZ coordinates of point along pointer vector with minimum error
PtErrorXYZ = (TP - PtEstGpt)*100; % Error to the actual target position
PtErrorMag = sqrt(sum((PtErrorXYZ'.^2))');
PtEstMag = 1.136 - Mt(:,11); % Distance from Board Plane to pointer
PtEstScl = PtEstMag ./ ptrAV(:,2); % Scaler to have Y pointer vector intersect plane
PtEstGz = ptrAV.*[PtEstScl,PtEstScl,PtEstScl] + Mt(:,10:12);

% Head Vector
HdAVa = Mt(:,4:6)-Mt(:,7:9);
HdAVMag = sqrt(sum((HdAVa'.^2)));
hdAV = HdAVa ./ [HdAVMag,HdAVMag,HdAVMag]; % Normalized head vector
HdTV = TP - Mt(:,4:6);
HdTVMag = sqrt(sum((HdTV'.^2)));
hdTV = HdTV ./ [HdTVMag,HdTVMag,HdTVMag]; % Normalized head to target vector
HdAdjScalY = HdAVMag/2;
HdEstAdjGz = Mt(:,4:6) - hdTV.*[HdAdjScalY,HdAdjScalY,HdAdjScalY]; %Position in head with target vector
HdEstAdjGzO = Mt(:,4:6) - hdAV.*[HdAdjScalY,HdAdjScalY,HdAdjScalY]; %Position in head with original vector
HdEstAdjGzT = [HdEstAdjGz, HdEstAdjGzO, HdEstAdjGz - HdEstAdjGzO];
HdAV = Mt(:,4:6)-Mt(:,7:9);
HdAVMag = sqrt(sum((HdAV'.^2)));
hdAV = HdAV ./ [HdAVMag,HdAVMag,HdAVMag];
HdTV = TP - Mt(:,4:6);
HdTVAvgXYM = (HdTV(:,1).^2+HdTV(:,2).^2).^0.5; %XYMag of head to target pointer vector
HdAVAvgXYM = (HdAV(:,1).^2+HdAV(:,2).^2).^0.5; %XYMag of actual pointer vector
AbHdXYError = radtodeg(acos(((HdTV(:,1).*HdAV(:,1))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgXYM.*HdAVAvgXYM)));
HdTVAvgZYM = (HdTV(:,3).^2+HdTV(:,2).^2).^0.5; %ZYMag of Head vector
HdAVAvgZYM = (HdAV(:,3).^2+HdAV(:,2).^2).^0.5; %ZYMag of head vector
AbHdZYError = radtodeg(acos(((HdTV(:,3).*HdAV(:,3))+(HdTV(:,2).*HdAV(:,2)))./(HdTVAvgZYM.*HdAVAvgZYM)));

ScalProj = dot(HdTV,hdAV,2); % Resturns the scaler projection magnitude for minimum error
SP = [ScalProj,ScalProj,ScalProj]; %Matrix formatting for multiplication
HdPGAvg = hdAV.*SP; %Scaled Pointer Vector
HdEstGpt = Mt(:,4:6) + HdPGAvg; %XYZ coordinates of point along pointer vector with minimum error
HdErrorXY = (TP - HdEstGpt)*100; %Error to the actual target position
HdErrorMag = sqrt(sum((HdErrorXY'.^2)));
HdEstMag = 1.136 - Mt(:,5); % Distance from Board Plane to head
HdEstScl = HdEstMag ./ hdAV(:,2); %Scaler to have Y head vector intersect plane
HdEstGz = hdAV.*[HdEstScl,HdEstScl,HdEstScl] + Mt(:,4:6);

Check = [HdEstGz];

if TGAvg > 0
    if PtErrorXYZ(:,1) > 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
end
end
else
    if PtErrorXYZ(:,1) < 0
        PtXYErrorOU = -AbPtrXYError;
    else
        PtXYErrorOU = AbPtrXYError;
    end
end

if PtErrorXYZ(:,1) > 0
    PtXYError = AbPtrXYError;
else
    PtXYError = -AbPtrXYError;
end

%for the head
if TGAvg > 0
    if HdErrorXYZ(:,1) > 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
else
    if HdErrorXYZ(:,1) < 0
        HdXYErrorOU = -AbHdXYError;
    else
        HdXYErrorOU = AbHdXYError;
    end
end

if TGAvg > 0
    if HdErrorXYZ(:,3) > 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
else
    if HdErrorXYZ(:,3) < 0
        HdZYErrorOU = -AbHdZYError;
    else
        HdZYErrorOU = AbHdZYError;
    end
end

if HdErrorXYZ(:,1) > 0
    HdXYError = AbHdXYError;
else
    HdXYError = -AbHdXYError;
end
if HdErrorXYZ(:,3) > 0
    HdZYError = AbHdZYError;
else
    HdZYError = -AbHdZYError;
end

%Format and redefine matrices
clear EL ER EGL EGR SP BGAvg
MT2{k} = [Mt, TGAvg, AbPtrXYError, PtErrorXYZ, PtXYError, PtXYErrorOU, HdErrorXYZ, AbHdXYError, HdXYError, AbHdZYError, HdZYError, HdXYErrorOU, HdZYErrorOU, HdEstGz, PtEstGz, TargetOrder];
%Moving average for determining closest value
X = 1;
if X == 1
A = 25;
Average = tsmovavg(MT2{k}(:,41),'s',A, 1); %'A' point moving average

[J,ri] = min(Average(:,1)); %Find row index (ri) of minimum value moving average
MT2{k} = MT2{k}(ri-(A-1):ri,:); %Select 'A' prior rows from the matrix
H{k} = [ri(1,1)]; %Log the selected row indices
RotPoint{k} = HdEstAdjGzT(ri-(A-1):ri,:);
MSTDaz{k} = std(MT2{k}(:,42));
MSTDEl{k} = std(MT2{k}(:,44));
if MSTDAz{k}(1,1) > 0.25
MTS{k} = [];
Y=1;
elseif MSTDEl{k}(1,1) > 0.25
MTS{k} = [];
Y=1;
else
MTS{k} = MT2{k};
Y=0;
end
if Y==0
MErr{k} = mean(MTS{k}(:,:));
MStd{k} = std(MTS{k}(:,:));
MR{k} = range(MTS{k}(:,:));
else
MErr{k} = [];
MStd{k} = [];
MR{k} = [];
end
end
%--------------------------------------------------------------------------------------------------
%Code to determine head correction HdError
if Y==0 && MTS{k}(1,27)==5 %Isolate the center Row
RotationPointElv{k} = RotPoint{k};
RotationPointElv{k} = [RotationPointElv{k}, MTS{k}(:,23)]; % Column 56 is target number
else
RotationPointElv{k} = [];
end
if Y == 0 && MTS{k}(1,28)==8 % Isolate the center column
RotationPointAz{k} = RotPoint{k};
RotationPointAz{k} = [RotationPointAz{k}, MTS{k}(:,23)]; % Column 56 is target number
else
    RotationPointAz{k} = [];
end
end
clear Tpx Tpy Tpz r L Target I2 I3 Mt ri Time T ScalProj EstMag EstScl I J ErrorR ErrorL
clear SPL SPR PGAvgL PGAvgR ScalProjL ScalProjR TGAvgL TGAvgR TP EstGL EstGR Average
clear ErrorMagL ErrorMagR EAvg EGAvg Error ErrorMag EstG EstGz A

%Convert the cell into one Matrix

MF = cell2mat(MTS');
MError = cell2mat(MErr');
MStDev = cell2mat(MStd');
MRg = cell2mat(MR');

MRotPointEl = cell2mat(RotationPointElv');
MRotPointAz = cell2mat(RotationPointAz');
MRotZ = mean([MRotPointEl(:,3),MRotPointEl(:,6),MRotPointEl(:,9)]);
MRotX = mean([MRotPointAz(:,1),MRotPointAz(:,4),MRotPointAz(:,7)]);
MRotYAz = mean([MRotPointAz(:,2),MRotPointAz(:,5),MRotPointAz(:,8)]);
MRotYEl = mean([MRotPointEl(:,2),MRotPointEl(:,5),MRotPointEl(:,8)]);
MRotY = (MRotYAz + MRotYEl)/2;
HdErrorRg = [max(MRotPointAz(:,7))-min(MRotPointAz(:,7)),
              max(MRotPointEl(:,9))-min(MRotPointEl(:,9))];
HdError = [MRotX(:,3),MRotY(:,3),MRotZ(:,3),HdErrorRg];
MSPSS = [MError(:,23:28),MError(:,32:53)];
MStaDev = [MStDev(:,42),MStDev(:,44)];
MRange = [MRg(:,42),MRg(:,44)];