Hearing what we see: Eye tracking as an augmented performance instrument.

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ABSTRACT

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Eye tracking technology has been developed in science to track the movement of the eye while viewing images or reading. This technology requires an extensive background in science to both design an experiment, and to interpret the data. The aim of the current thesis is to investigate simple and approachable methods for the application of this technology in an artwork about the nature of looking. I created a performance art project to test the application of eye tracking towards constructing an instrument that expresses visual sounds in a performance. To accomplish this, I modified a method for low cost eye tracking to make a set of sound performing eyeglasses. This project showed that it is possible to use eye tracking outside of science in a artistic performance in novel ways, but also demonstrates that this technology could be further developed towards not only solo artistic performances, but also towards other installation artworks that involve the spectator.

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> In order correctly to define art, it is necessary, first of all to cease to consider it as a means of pleasure, and to consider it as one of the conditions of human life (Tolstoy, 1904, p. 47).

Eye tracking, that is the detection of the movement of the human eye, has been used by researchers in many areas to investigate how humans use their eyes while performing natural tasks (Land & Tatler, 2011). Modern commercial research areas include web usability studies that show where the viewer focuses their gaze on a web site (Neilsen, 2009) to determine which instructions were looked at while people learned to navigate the user interfaces for video games so that instructions in games could be designed based on the user's experience (Lee, 2011). More interesting for this thesis artistic research is that eye tracking has become a widely used technology in the field of psychology, allowing for a direct link between perception and attention in reading and visual search studies (see Land & Tatler, 2011 for an extensive review). One of the benefits shown in these visual search studies' methods of eye tracking is that not only can you passively record the position of the eye as a person views a stimulus, but it is also possible to use these eye movements to change the properties of the stimulus. This feature, termed gaze-contingent manipulation, has been used in psychology to investigate the characteristics of eye movements (Rayner, 1998), while simulating visual disorders, such as age-related macular degeneration (Johnson &Gurnsey, 2010) to investigate new ways of moving the eye to compensate for this disease. These characteristics of eye movements are of interest to this research because while they are movements of the body that we do not consciously consider in our everyday activities, they influence the way we see the world.

But reviews of eye tracking studies, such as Rayner's (1998) summary of current eye tracking investigations in psychology, indicate that simply measuring the movements of the eye, such as the duration of the gaze per word or the order of fixations and re-fixations on each word in a sentence, is not enough to understand the mind's physical connection to the eye. As an example, Rayner (1998) found that re-reading a word, called a regression, occurs when it was not fully understood on the initial fixation. When he states, "It thus appears that any single measure of processing time per word is a pale reflection of the reality of cognitive processing" (p 377), Rayner recognizes in his study that there are many factors, internal and external, influencing eye movement like centralizing the focus on a specific word within a sentence for a better understanding of the meaning of a word. Here we can understand that a person's intentions influence what and how they see. To understand what influences the movement of the eye it is necessary to consider what the eye is 'being' directed at. The directed movement of the eye is a key investigation for this research because spectators' visual interest in artwork has a direct influence on the way the body moves.

In a study at the National Gallery of London (Wooding, 2002), an eye tracker was left in front of images of two paintings, *Christ addressing a kneeling woman* by Paolo Veronese (about 1546) and *The Origin of the Milky Way* by Jacopo Tintoretto (1575 to 1580). Instead of dwell time, this research studied traces to see the paths that the eye was focused on in the paintings. The results show the paths that cover similar areas on the image across different viewers. In this study we see that a generalized 'area of interest' on visual artwork could be determined by following where a person looks. Eye tracking is used in this study about where the eye looks on an image for exploring what is interesting to people in a painting.

But what about eye tracking as a tool, or an instrument that expresses what is being looked at in live artworks and for other applications? There is a wide body of research about eye tracking and its use as a tool in writing, for psychological inquiry about sketching, and also for understanding the self.

In addition to investigating how people perceive stimuli or in the gaze-contingent changing of the stimuli, eye tracking has been used as a direct control device for an individual to draw words and images. For example, a device such as the EyeWriter (The EyeWriter, n.d.) is an eye-tracking instrument that enables the user to draw lines and letters on a computer screen with their moving eye. This technology has been used in art to allow individuals who have a muscular disease, the ability to interact with the world and produce art. Here we can understand that the activity of 'looking' can be digitally quantified in real-time into data for outputting and manipulating external events, such as drawing a line. Clearly, in this respect, the action of the mind is connected with the body so that we have control over where we choose to move our eyes for in time and space.

In combination with our other systems, like the motor system, the eyes provide a 'look-ahead' function by directing the view toward information about future locations in the visual scene. This type of information is stored in memory to guide a sequence of actions (Land, 2009) toward completing an end goal. For example Land (2009) discusses the characteristics of eye movements while a person is sketching. In the activity of sketching, drawing a line consists of looking at the point of origin on the object, and then to the point of termination of the target line on the sketch before completing the action of drawing the line. This type of directed eye movement demonstrates that we move our eyes to understand and navigate the visual scene as a part of the process of a person's perception or understanding about the goal of their task. In this respect, eye tracking is a method for studying our visual process of goal directed interest.

Similarly other eye tracking studies demonstrated the characteristic of the gaze relative to the time we spend looking at something and the order of the points in the scene that are focused on by the eye as a measure for the activity of our thoughts (Glucksberg & Rubio-Fernandez, 2011). When someone is watching another person's actions, their eyes' movement is directed to fixate on locations in the visual field relative to their understanding of where another person with different knowledge may be looking. For example, in 2011, Glucksberg & Rubio-Fernandez's research describes a classic task where a person is looking at a scene with two characters, Sally and Anne. In this Sally and Anne task, an object is hidden from Sally while Anne watches. When Anne is asked where Sally thinks the doll is, eye tracking shows that the person looks at the point where Sally thinks the object is and then looks at where the object really is. This scenario describes a term called *Theory of Mind (TOM)* as our ability to understand an event in light of oneself and others' perspective or knowledge. There are many definitions for this concept, but it interesting to consider how our feelings can be linked to eye movement, and that we can physically measure or quantify a person's gaze with eye tracking.

The eye movements that are studied and tracked most frequently are those that are directed by a person's visual interests and goals. Eye tracking technology has been used as a tool in writing, for psychological inquiry about tasks like sketching, and our own understanding of ourselves and others. The examples using eye tracking as a tool show that this technology can be adapted for inquiries across various disciplines. As an artist, it would be interesting if we could literally listen to another individual's TOM. In this respect, my artistic research thesis project seeks to translate the data of eye tracking into sound, by creating a sound compostion based on a play of time where, more precisely, the sounds in the composition represent the time spent gazing at something. In this project, the goal is to measure the duration and position of the gaze as a numerical value and transform this data into the frequency of the playback of a sound as a possible way to "listen in", and to hear the nature of looking.

But what would we hear from the sound of looking? There is a wide range of research documenting activity in specific areas of the brain relative to our perception of specific events, such as the sound of a word. Most recently, a document from the Berkeley News Centre website reports that scientists matched a spectrogram image of a sound sample wave to the image scan of a person's brain wave activity while they were listening to those same sounds (Saunders, 2012). The results from the study methods output coloured images according to the brain's wave frequencies that are visually similar to a computer generated frequency image of the audio recording of that same sound. It could be that the brain's activity responds like a specialized recording system for sensory specific events, like sound. Studies such as this show that we have direct physical 'environment-body' interactions, for hearing sound, in the environment, and we can image these interactions with a computer.

Similar to imaging the activity of sound in the brain, eye tracking should enable physical imaging for observation of directed visual system activity. For example, if the duration that the gaze stays directed at one point in the visual scene is measured using eye tracking then this information (time spent looking) could be the time and frequency that a sound is played in a composition. A sound expressed from another person would be imaged similarly across different people and projecting sounds based on the eye tracking data from one person would activate a visual listening system for observers to hear that person's perspective.

Within the individual the collision of simultaneous auditory and visual events can give rise to interesting perceptual effects, where an individual's perception can be changed or distorted by the combination of different stimuli. For example, in the McGurk Effect (McGurk & McDonald, 1976), when an auditory stimulus of the word 'ba-ba' is paired with a video stimulus of an person's mouth moving to produce the word 'ga-ga', what is perceived is not either of these words, but instead a new word: 'da-da'. In this instance the presentation of conflicting auditory and visual information produces a interpretation of what is perceived in reality. This type of combined sensory cross-over produces sensory conflict where the brain must make sense of information, and in instances like the example of the McGurk Effect, the final perception is put together by combining and interpreting different modalities, such as vision and hearing. But between individuals, on the other hand, sensing another individuals' perception would give rise to sensory enhancement. Hearing what is being looked at by someone else would be an additional or secondary source of sensory perception. Hearing through the eyes of another would require some sort of device to translate the movement of the eye into the sound so that new interpretations of the meaning could be understood. For example, hearing a note for a duration of time could be associated with a characteristic in the visual scene of the performer holding their gaze at a point of interest.

My artistic performances create a moving sculpture using a body (or persona) that travels within an electro acoustic passage. The persona is an identity, a characteristic or quality of an individual that I express with my body movement. For example, wringing the hands would be a type of body movement that expresses the characteristic of worry. During a performance, this work relies on techniques for movement improvisation, accompanied by sound and images using costume and the performance space. My artistic research approach seeks to integrate the role of a musician and performer in works that consider ways of making sound with the body. In this respect, it would be interesting to consider using eye tracking technology as an instrument played in a performance. In the artistic approach for this thesis I am seeking produce an artistic composition that uses the movement of eye to express the feelings of the individual.

In light of the many different ways that eye tracking has been used in past research on visual interest, the way the eye moves and also the way that we understand events by re-imaging sensory information in the brain, this thesis asks how the moving eye can play an instrument in a performance. This research generally asks if it is possible that an eye tracking instrument will enable us to hear what we see. This question will be explored by determining how a new technological instrument can be built to sound out eye movement, and what these sounds can be associated with. Perhaps eye tracking can help us to relate to our human nature, by hearing sounds that express the nature of looking.

Thesis research question

If psychologically the eye moves depending on the mood or goal of the person, such as when an artist is looking at specific points on a person's face while sketching a portrait (see Land, 2009), and if physically we can track the eye movement and gaze duration during a goal directed activity or interest in the visual scene, then is it possible to use eye-tracking technology in an audio-visual artwork to express the combined psychological and physical nature of looking? This thesis hypothesizes that with an eye-tracking instrument we can perform our visual observations by tracking the movement of the eye while a person is looking at something and measure that duration and position of the gaze relative to a point in space, like on a grid. This research art project expands the activity of the eye as a sonic instrument in the artwork by redirecting this data, to modulate sound by the duration or position of the gaze. In this way, this art project outputs the sound of looking, as a projection of the changes in a sound relative to the changes of the performer's eye movements and gaze duration.

Within the structure of an artistic set-up, this research asks how can we implement eye tracking indirectly in performance as a way of expressing the sound of the activity of looking. Investigations that use eye tracking demonstrate how this technology has been successfully integrated into commercial and psychological research. In turn, the use of eye tracking technology in research can be adapted in an art project to track a performer's way of looking. Creating a performance that considers the act looking would be useful for designing and constructing an instrument that links the movement of the eye with sound. This type of performance would also be a way to artistically express the visual interest of the individual.

It is expected that we can enhance the act of looking using sound in an artistic work. The project description demonstrates that we can hear the changes in sounds relative to the points of visual interest that are associated with the where the eye moves. It is also expected that it is possible to incorporate the eye-tracking instrument as part of an artwork.

The method for this inquiry is a creative process combined with research. Broadly speaking, any question of integrating an eye-tracking-user-interface as an expressive tool, should consider the eye as way of using the body as an instrument from a combined approach that includes a research investigation and a review of artistic applications toward the creation of a performance artwork using an eye tracking instrument. For this reason, the approach for thesis project will be to use eye tracking as a tool to create a performance artwork. This artwork's method will be expanded in the following procedure:

1. Investigate concepts in eye movement research that studies the visual mechanics of our bodies while sensing what is of interest in the environment. In this way, we can imagine a new sustainable instrument as a dual-purpose user interest and controller device that can also be used in future performances and artistic works.

2. Review the research about the use of the body for controlling parameters in performances and other artworks. This research review includes other artistic approaches toward the use of the body for sound performance.

3. Create a performance that integrates an eye tracking instrument for the projection of sound in a space. The title for this art project is, "Hearing what we see." In the performance, the eye tracking instrument will track the eye as a person is looking and

the movement of the tracked eye will be used as a sound controller to play sounds for spectators to hear.

This artist research considers a way to integrate eye tracking with an improvisational style in my current artistic practice. For this reason, the approach for this thesis is to create a human-computer system that captures the movement of the eye and to translate this movement into sound in real time. It should be noted here that the movement of the eye will vary depending on what the user is interested in looking at in the visual scene. This means that the position of the eye will vary in the physical duration and place on a point in space. Because we have no way of knowing for certain what or where a person will be looking at any given time, the varying sounds expressed by the instrument will be emitted improvisationally, in real-time, relative to the varying movement of the eye being tracked. As a result, the sounds from this instrument reflect the movement of the eye that is directed by the performer’s momentary feelings and interest in the points located and looked at in the visual scene.

Background information

Concepts about eye movement

This thesis project incorporates within a performance the sensory activity of looking. Within the performance framework a few key concepts are included in this discussion to connect eye tracking and looking. The following concepts about the physical characteristic of eye movement help our understanding of the uses and benefits of the eye tracking instrument for performing sounds in an artwork.

One key concept is that eye movements can be tracked as the changing x and y coordinates of the movement of the centre of the eye pupil across the perspective of the visual scene. This mapping data can be redirected as numerical values to modify the quality of a sound, such as for changing its frequency. With eye tracking the current thesis will focus on mapping the eye movements made while looking at the environment for this project's performance artwork.

To integrate an instrument played by the eye, we should be considering that looking is connected to the eyes' physical processing of a specific external property of the world in the most direct way. Looking allows us to match visual sensations from our memories with information gathered by the directed use of the gaze duration and position of the eye. We recognize the colour 'red' by the stimulation of pigment in the eye's photoreceptors that are designed to react only to light waves in the range of 550 nm (Llinás, 2002). Using a microscope we can observe each of our sensory organ's chemical transformations of energy into nerve pulses that extend into the brain (Blake & Sekuler, 2005), such as when light waves hit the rod and cone receptors on the eye's retina, or when sound waves move and depolarize the cilia on the basilar membrane inside the cochlea of the ear. Thus the physical characteristics of looking and the transformations in the eye are maintained in memories that are different for each of us depending on our different points of view. For example, one might see a darker rose when standing in the shadow or a lighter coloured rose when standing in the sun. This means that the experience of reality is different for each of us because information like the colours contained in a visual artwork become sustained in our memory by the types of sensations, such as light wave frequencies, that we observe and experience egotistically (from our own body) relative to an object or event in the ongoing present, past and future.

Other early remarkable methods demonstrated the physical nature of looking such as when we are looking for specific visual information, such as figures or shapes. Alfred Yarbus (1967) successfully recorded a person's eye movements while looking at the painting "They Did Not Expect Him" using experimental systems such as the reflection of a beam of light pointed at the centre of the eye to trace a scan path on a piece of light sensitive paper. Using this method, Yarbus also asked what the people in the picture were doing and he overlaid the traces onto the original picture. Yarbus' study results showed that there are specific areas like shapes or figures within the picture where the same person's eye was positioned the most. What is most evident in the trace images is that we gather information from the world by looking at the most informative areas of the visual scene. Looking is the way we use our visual sensory mechanism in the most efficient manner. Instead of focusing on the whole visual scene, we direct our eyes to focus on key areas and the eye is moved spatially to look specifically at something. It is most likely that what a person is looking at is connected to a point of interest in the visual scene. In this way, the instrument for this thesis' project can be used to gather visual information specific to looking.

But what drives eye movements? The eyes are directed in both bottom up and top down approaches. Bottom up processing refers to an external feature that stands out and grabs our attention. Top down processing is the internally directed way attention is focused to look at something.

In the bottom up approach, interesting points are determined by the least and the most grouped features. In this way, features are arranged by Gestalt principles, such as proximity, colour or orientation. The groups of features stand out in the visual field and become salient to our attention in a 'winner takes all' approach (Koch & Ullman, 1985) and the most interesting area in the field of view elicits the eyes to move.

Salient features are interesting because they stand out in a meaningful way from the rest of the ongoing world (Knudsen, 2007). This could be a flash of an approaching car from the periphery or a change in the colour of a light from red to green. Eye movements are directed by the decisions made from working memory to improve the capture of salient information in the field of view.

But salience alone is too general for accurately predicting where the eye moves. There are other influences on the way we move our eyes and some types of eye movements have a tendency to be employed more than others (Tatler, 2009). For example there is a tendency to make more small saccades closer to a target location. This means that the more fixations are localized in an area over time, the more salient features surface in that fixated area. Another tendency is the greater occurance of horizontal eye movements than vertical, because in the real world, not much is going on up in the sky.

The environmental situation also influences how we move the eyes, such as when navigating the grocery aisle and scanning accross the shelves for a specific product.

In 2005, Hayhoe & Ballard found that the eye is positioned toward the area that is not only most visually salient, but also task relevant. Most irrelevant visual information is not looked at. In this way, top down directives link several fixations over time to the task being performed. Examples discussed in the research by Hayhoe and Ballard (2005) note that some fixations occur in advance of the completion a task as if predicting future locations or events, such as looking for the bread to make a sandwich or looking at an approaching ball before attempting to strike with a bat. The look ahead function of eye movement relative to the goal of the task is interesting because it shows how the visual system can accommodate both external and internal directives. Clearly, eye movements occur as a combination of bottom up and top down processing. The goal of these movements is robust, such as for investigating the unknown, for navigating a kitchen to make a sandwich, for playing a game, and for creating artwork.

In this project the different types of eye tracking data should be considered. Studies about eye tracking have classified different types of eye movements. The types of movements central to my discussion are the eye movements called saccades, pursuit and fixations because they can be quantified in information processing tasks by tracking the x and y position of the centre point of the pupil and the duration that the eye remains relatively stationary in one position. Saccades, pursuit and fixations can be defined as different types of eye movements and are described in peer-reviewed research (Rayner, 1998). Saccades are rapid eye movements, that are like quick jumps from one point to another in the visual field. We make saccades for refining acuity. During saccades there is hardly any information taken in because these movements are so fast that anything we see would be a blur. This aspect of saccadic eye movement is called ‘saccadic suppression’ (Rayner, 1998). Saccades help to position the eye for focusing attention on something. According to Rayner’s (1998) review, pursuit eye movements occur when the eye is following a moving target. Pursuits are slower than saccades and visual input is less reduced than during a saccade. Fixations are the focal points in the visual scene where the eye remains relatively still and most information is taken in (Rayner, 1998). The average duration of a fixation, such as while reading or perceiving a scene, is about 200-300 ms (Rayner, 1998). Along with scanning patterns, such as those that are associated with a generalized area of visual interest in artwork (Wooding, 2002), saccades, pursuits and fixations are types of eye movements that are centralized around what is interesting in the visual field.

When viewing artwork, the way a person examines a pictoral scene is influenced by both bottom up and top down processes. In pictures where artists have embedded indistinguishable images, fixations are focused on an area when a viewer detects a hidden image. Eye tracking conveys a viewer’s perception relative to the manner in which a pictoral image expressed by the artist is realized.

Because this project includes the sound made by the performance of the instrument, it should be noted that similar to visually sensing, the instrument sound is beneficial to the art project because what we are listening to can provide details, such as spatial information from echoes and reverberations. In this way, we gather knowledge by means of the ear. Colin Griffiths (2003) writes that listening is an active state. His writing describes the sounds of Vancouver’s harbour front, the distant train, and the characteristics of the sound of open spaces. Griffiths' writing indicates that when we listen, sounds are attended to, assigned meaningful relationships to their cause or significance, and through his descriptions, we understand where we are.

Roland Barthes (1985) writes that listening is "signifying" (p. 246) and this process of understanding is a "function of intelligence…" (p. 247) and it shows our ability to "decipher reality" (p. 249). Listening is that part of us that filters sonic information in the search for meaning and subsequently, Barthes' writing describes that hearing, after listening, is the result so that listening would require not only activity but also significance in order to observe the ongoing world relative to our needs and interests.

We can control our senses to observe simultaneously and selectively. We just don't sit there and passively take in whatever stimuli happens to be in one or all of our sensory receptive fields. In this respect, auditory sensory experience is also selective. For example, a phenomenon called the Cocktail Party Effect (2012) describes that a listener can pay attention and understand the words of a single voice in a crowd. This effect highlights the fact that we can filter and observe specific details in the environment around us. In this way artists' methods can selectively present sensations, such as a motif in an orchestral work, to express a specific idea as a predetermined sensory profile for an observer's experience. The sensory details we recognize give us a sense of place and allow us to see the expression in a dancer's gesture or to hear the melody of a voice.

The concepts of the physical nature and the goal directedness of looking combined with the informativeness and selectiveness of listening provide an approach in this project's method. Visual data from the instrument, such as the change in position of the eye or the duration of a fixation, is gathered relative to what the user finds interesting.

If this data is assigned to sounds, then listening would also be interesting because the sounds would have a direct connection to a person's visual points of interest. In this way we can consider that this instrument would express looking in terms of spatial characteristics and in this respect, the purpose of crossing one sense with another is an active multisensory understanding.

Combining visual sensations with sound creates new expressions. In his writings, Jean Luc Nancy (2007), discusses the senses in terms of understanding an idea, and also by Gestalt principles such as grouping sensations into a figure and background. Listening attempts to "capture" the auditory sensations and we can gain an understanding of the world in terms of the sensations we experience. Nancy (2007) notes that the senses evoke a vision, or a form that is sonorous. Looking and listening are deciphering, signifying and perceiving, and are a directed activity that requires our attention. Through the process of defining of an image Nancy (2007) also combines the two faculties into a concept of a visual sound, as one image, when they are understood.

Looking and listening are connected as internal images. What we are looking for is visual information, such as figures or shapes. What we are listening to provides sonic information, such as the subtle echoes of reverberating spatial information or a sense of one's position in a place. Both looking and listening are activities with a purpose for capturing space. A part of this art project's methodology will be designed for capturing looking with an auditory scene in performance. The activity of looking leads to a new single unit of expression for listening, and this concept leads to a new type of instrument.

The ideal instrument is reasoned in Nancy's (2007) description of visual sounds, but how does one put this type of instrument into a work? The ideal instrument should be able to express modern sounds imagined by today's composer. Art and music composition use numerous processes to attempt to recreate a scene. There are many expressions to create and too few instruments to adequately reflect human sensory activity. This inadequacy is an area for continued exploration in the creation of a new instrument. Edgar Varese (1966) wrote about the concept of a compositional tool that involves "zones of intensity" that vary in timbre and loudness. He describes these zones as the perfect way to compose, where it is possible to use any sound conceivable. But he further describes the existence of a great problem: how to transpose what the composer intends? From this description, if we consider that this project seeks to transpose the activity of looking toward different intensities of sounds for listening, we can realize that it would be possible for a sensory produced sound to be written into a composition, by using zones of intensity of the frequency and duration of the sounds influenced by the eye tracking data.

To consider compositional zones for this project, the data obtained by the instrument should be reliable and actually be tracking the eye and gathering the right information, such as duration and gaze position. Also, the output of the data should be able to be generalized so that everyone can hear the sounds similarly in the performance.

Generalized sensory interfaces are present in our everyday society. Sensory substitution is a strategy used for extending the use of the body with different technologies. For example, the 'AcceleGlove' was demonstrated for CBC news (Hartman, 2009) to show how a hand performing sign language could be transposed into the sounds of spoken words. A well known way that we can compensate for vision loss in reading, is with the use of touch such as in the system of Braille for reading or the less well known language called Vibratese: a language for communication using different vibrations transmitted through touch (Pasquero, 2009). These practical examples describe devices that involve using the senses in novel ways. These examples also demonstrate that with the progress of technology present in our society there is continuous creation of assistive devices and new instruments for the body.

One criteria for the data of an instrument that outputs visual sounds is that it should be able to capture the path of looking relative to a particular visual scene. For example, modern products such as the Tobi eye tracking system use dual cameras for head, eye, eyelid, lip and facial tracking. A system like this one was integrated into the dashboard of a car for following a person's eye movements while driving. This type of system produces a video that is used to create line maps that show the movement of the eye's gaze during a period of time while looking at a scene of interest (Seeing Machines, 2012).

Another criteria for the data of an instrument that outputs visual sounds is that the sounds output via the instrument should be perceived similarly by everyone who listens. Al Bregman (1990) studied and documented the auditory perception of sounds in the world, like glides (increasing frequency tones). What is interesting in his conclusion of Auditory Scene Analysis is that he notes a dichotomy of meaning. In the "same" listening environment, we all generally come to the same conclusion about the characteristics of sound such as a sound that glides upwards sounds upwards to everyone. On the other hand there may be variations in listening because even with the same optimal conditions, we bring to the experiment individual differences: experience, practice, cultural background for interpretation, preference, mood, distraction of the surroundings etc. (Bregman, 1990, Chapter 8).

An ideal instrument for creating visual sounds would be with the use of eye tracking. The studies using the Tobi Tracker (2012) and set-ups that allow tracing the movement the eye relative to an image by Yarbus (1967) show that the eye can move in a specific way when looking at something of interest and that we can successfully track this movement among different people. Also, if our perception of the characteristics of sound can be recognized similarly by everyone, then perhaps using the eye to create sound points would be a practical artistic confrontation of one sense by another, not for judging or evaluation but as an enhancement to what we normally have seen in composed works: sights for the eye and sounds for the ear. By identifying and re-associating the activity of looking for the activity of listening in one artistic work, the resulting set-up based on the background concepts for eye movement would produce sights for the ear, a new type of artistic expression for use in my performance work.

The final art project for this thesis is a modern instrument, where the parameters of the construction are tailored for the involvement of the activity of eye movements with sound. This instrument is an electro-acoustic performing object that expands our abilities and permits a new way of expressing and conversing with each other using a non-traditional sensory instrument. If as Bregman notes, sounds are evaluated similarly by all but also individually according to one’s perspective, then it is possible to create the ideal instrument, using eye tracking as an ideal instrument for performing visual sounds for individual listeners among spectators attending a performance.

Artistic approaches to tracking human movement.

Eye movements alone can be expressions in themselves, like the rolling of the eyeballs in the movements for Indian traditional dance called Drishthi Bheda (Nandan, 2009). Another type of movement made to express something in sound is playing the notes of a scale of an instrument. This type of movement is a communicative gesture. (Jensenius, Wanderley, Godoy, & Leman, 2010). The approach for eye tracking in this thesis is to track the movement of the eye while looking at the ongoing world.

What directs the eye to wander towards different points in a natural scene? Eye tracking has been used in studies exploring the characteristics of the visual scene that draw a person's gaze when watching people walk. A point light walker is a video of a person walking with points of light fixed to their joints. The video is filmed in the dark so that only the points of light are visible in the movie. The study by Saunders, Williamson & Troje (2010) used eye tracking with point light walkers to determine at what points on the human body the viewers were looking at when asked to determine the gender or direction of the walker. They showed that the eyes were fixated more on the feet when asked to determine the direction of the walker or on the shoulders to determine the gender of the walkers. This study shows that we can understand the characteristics of a person walking by looking at a few specific points of moving information. The gaze is linked to the activity of our visual attention. Only the useful information in the world can hold a person's gaze.

Eye movement can be followed using mechanical devices, direct observation, and cameras with computer programs. These methods facilitate observation of another person's sensory activity in novel platforms. Multi-media artists create works for emphasizing an experience for audience members from diverse backgrounds. This brief review of eye tracking research indicates that while tracking looking, human eye movement can be used as a controller for sound in this project's final art project.

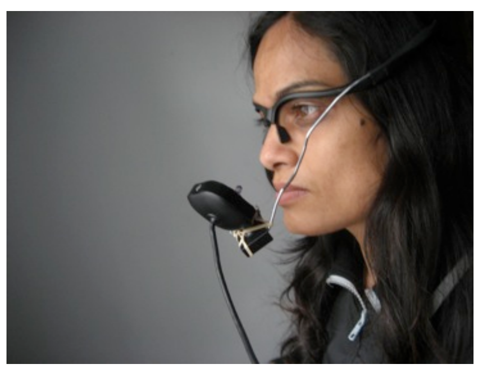
Video camera tracking technology has been used in more than one artist's works. For example, Lynn Hershman presented a box with a peephole that used a camera to re-project the viewer's looking eyes into the artistic work itself. Depending on where the viewer is looking, different segments of videos play in a box that is decorated like a miniature bedroom. In this work, the act of looking changed what videos were played back during the experience of their observation (Gagnon, 2000).

Other artists use tracking for sound. For example, Andrea Polli (2001) created sound from the energy fluctuations of the sun's light waves. She then used a camera to track a person's eye movements to manipulate these sounds for audio-video performance where the audience could experience a sonic accompaniment of the light waves of the sun. David Rokeby's artwork, "The Very Nervous System" (1990) uses a small camera to control sound parameters while tracking the whole body. Like an orchestral conductor, a hand movement in the air would trigger the playback of a sound file. In this work, whole body tracking directs sound playback where different body movements dictate the sounds the user desires to hear at a given moment in their performance.

Artistic projects that used camera tracking, like Hershman's peephole or Polli's sun gazing and Rokeby's body controller, provide practical examples of using the movement of the eye toward a point to elicit changes of the video within the work, the movement of the eye as an instrument for performing sounds, and the use of the body as a controller that can freely manipulate sounds in a performance. These past artistic works indicate how eye movement can be connected to sound in my artwork by using eye tracking to sound out looking by incorporating the movements we make naturally in response to what is visually interesting in the environment. In this way, real world events would provide more insight to the sensory activity that is directed by the mind.

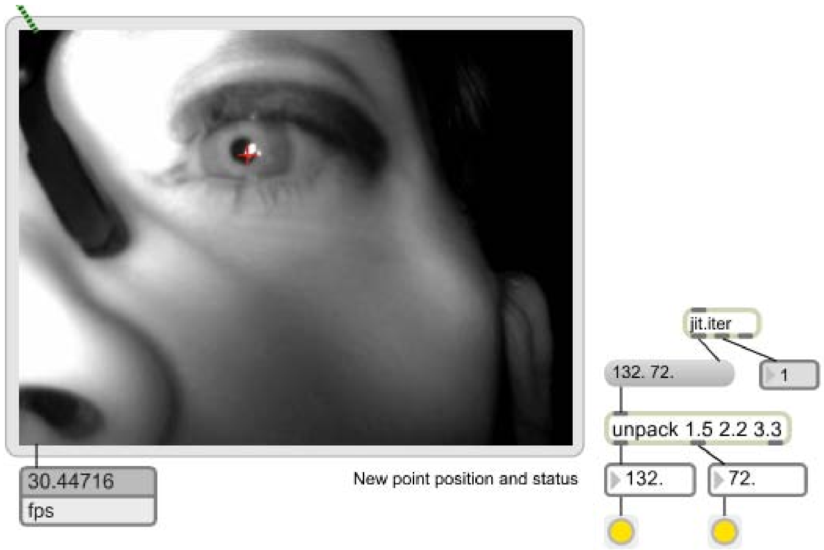
During the preliminary research for this thesis project I constructed a pair of eye tracking glasses and tested the device for transferring the tracking data into sound. These head-mounted eye tracking glasses have demonstrated to me that it is possible to explore low cost eye tracking for this project. But there are many obstacles for the participants who use this system. The apparatus itself is not good for novices. Prior training is required for holding a fixed head position and calibrating the tracking of the eye within the programming environment. Similar to any other musical tool, using this instrument requires practice.

Figure 1. Photo of a head mounted eye-tracking camera.



A set of infrared camera glasses has been constructed for preliminary research for the eye tracking. Tests on the USB video input have shown to provide useable eye position information in Max/Msp/Jitter.

Figure 2. Screen shot of video showing eye tracking in Max/Msp/Jitter



This project now explores the activity of looking for listening. The visual scene when being viewed can be used as a compositional guide for changes in eye position. These changes can be made into changing sounds heard in the piece.

Method

This section presents a research creation project method as the approach used to determine whether eye tracking can be used in a performance. In my method, I am combining eye tracking research from the fields of psychology, music and art with my artistic practice in performance and music to build an eye tracking instrument. In this way, my approach uses investigation and experimentation for the final performance artwork to design an ideal eye tracking instrument that projects sound to an audience.

The final design of the eye tracking instrument evolved through a series of prototypes. For a visual overview of these prototypes, refer to Appendix 1. The first set of prototypes were hand-held eye tracking boxes made out of cardboard and clear plexiglass with peep holes on one side that the user could peer into it. Inside the boxes, a small camera was positioned toward the user's eye and could be used to track the eye as the user looked through the eye holes at images placed inside the box. Another prototype was a stationary standing mask with eye holes so that the user could peer into the mask and a camera could track the user's eye from the opposite side of the mask. These early prototypes showed that it was too difficult to hold a steady video stream of the moving eye for consistent eye tracking, therefore the final prototype that I built was a pair of glasses. The glasses held the camera and could be fixed onto the user's head with relatively reliable eye tracking. This set of eye tracking glasses is embedded in a performance of body movements practiced for enhancing the activity of looking while using this constructed eye tracking instrument. In this way, I developed the visual-sound instrument as a part of the system for creating the art project.

An outcome for this project is a system for integrating the the performer with the eye tracking and audio technology. This system can be used to make visual sounds in future performance and installation artworks. The following is an outline for a performance with a system for integrating the eye tracking instrument.

Performance description, materials and concept.

Title. The title for this performance of this thesis performance is “Coeur du poulet”. It refers to revealing the seeing of the performer. The duration is 10 minutes. The theme for this piece is looking.

Performer. Zorina Bacchus

Performance materials. The visual-sound instrument requires one MacBookPro (2011) with a 25 ft. USB extending cable that attaches to a Microsoft 2000 web camera. The camera set-up from the preliminary research (see Figure 2) was modified to fit into a pair of eyeglasses made of 1/8-inch plywood. These eyeglasses are for holding a small tracking camera pointed toward one of the looking eyes of the performer.

Concept explanation. This performance plays on our feelings associated with being looked at, such as by a stranger sitting across from you on a train or subway. This activity is intensified as a sonic and visual expression while the performer wanders without direction through the audience as if guided by what the eye is looking at. The performer is the identity of “the one who looks”. White body make-up, clothing and light colored hair is used to transform the real character of the performer from the every day individual into the character of one who looks. The costume and makeup are designed to reflect a simplification of the characters within one person, down to an “eyes only” persona . In this way, the visual sound instrument is embedded into a live performance where the movement of the looking eye is transmitted into sound projections with the use of the eye tracking glasses.

Eye tracking data and description of the transformation of the data into sound.

The tracking field is defined as the visible area relative to front of the eye. The changes of the focal point are x and y coordinates of the moving eye's changing points of focus on locations within this visible image. The user data is streamed in real-time to designate the playback speed of pre-recorded sound clips. In this project the sounds designated to be modified by the eye movements are a cricket chirp and a single snare drum hit. Both of these sounds are from living movement (the insect and a person's hand striking a drum). These sounds are well suited for modification during the performance because they are semi-transient sounds that would result in bursts of sound in varying durations and these types of rate variations in sound are easy to distinguish.

Figure 3. Screen image of programming for video capture of moving eye and mapping of centre point of eye to x and y position data.

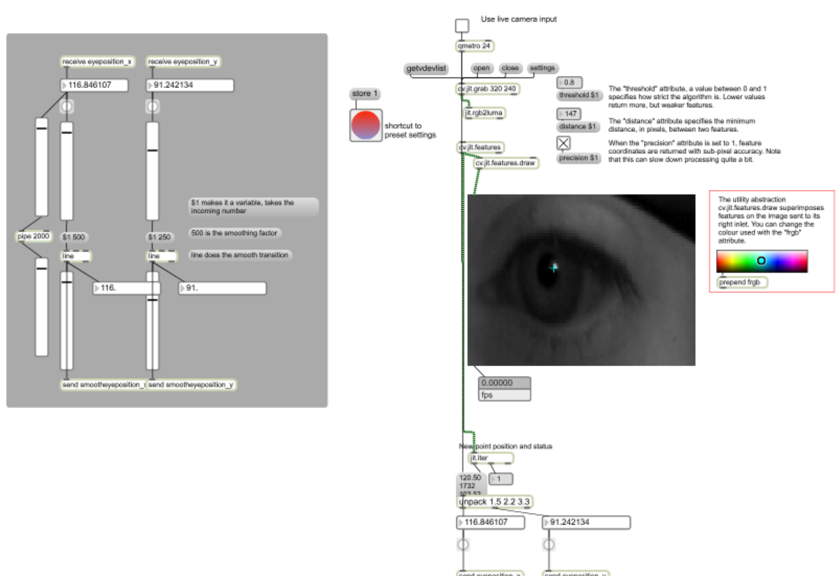
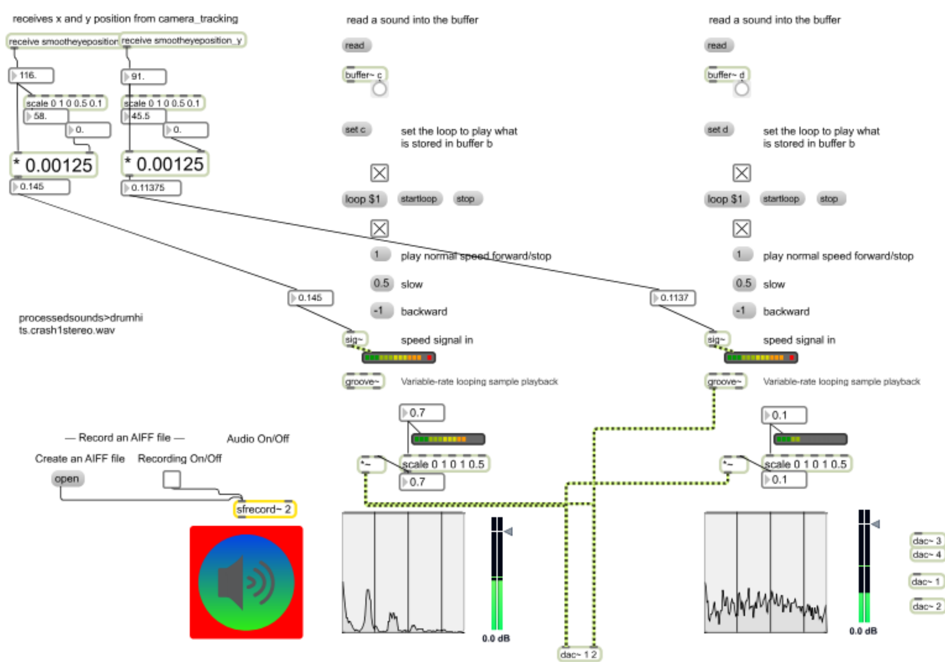
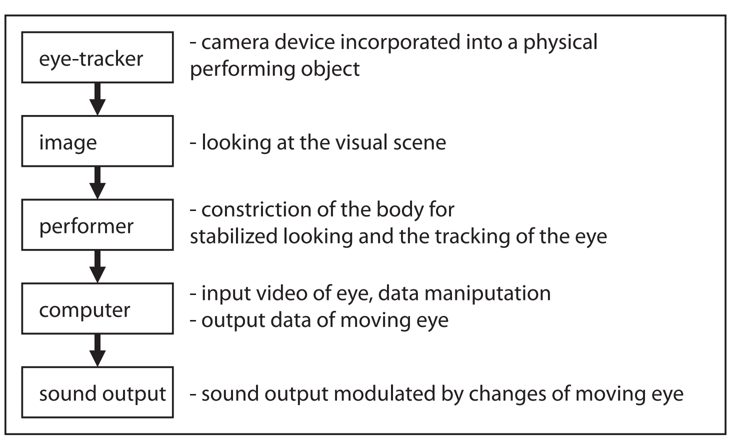


Figure 4. Screen image of programming for streaming x and y eye tracking data to modify the play back rate of sound clips.



System. This system will permit the performer to play visual sounds and to have live (real-time) interaction with the computer without touching the keyboard. This system allows for improvisation with variety during the performing situation.

Figure 5. System diagram for a performance instrument for expressing visual sounds



Results

Research on mechanical sound in music stress that "machine sounds helped to evoke the quintessence of life" (Bijsterveld, K., 2008. p. 140). This project created an electro acoustic environment with pre-recorded sounds mixed with electronic instruments. The live performance included using the eye-tracking device to mix the sounds in real-time.

Sound projection documentation and description.

To prepare for the live performance and operation of the eye-tracking device, I tested the eye tracking apparatus in one of the large open studio spaces at Concordia University EV building using loudspeakers provided on site. For a sample sound recording of the cricket sounds modulated with the eye-tracking device during this testing situation, please refer to the included sound file. This file is provided with a copy of this PDF entitled 'ZBacchus_eyeTrackerWithCricket.WAV'. This file can also be referred to online through the following link: https://soundcloud.com/zoeb/eyetrackerwithcricket

The data obtained from the eye movements were the raw x and y positions of the centre point of the eye, the pupil. This changing centre point of the tracked moving eye of the performer was the x or y value that changed the rate of the playback of the sound clips. This process created a voice-like quality from the projection speakers where the sounds increased, and decreased in pitch as the change in the x or y value increased or decreased with the movement of the performer's eye. The longer the x and y values remained constant, the longer the clip was played at a specific rate.

In the construction of the art project, the eye-tracking instrument noticeably modulated the frequency of the sound of the cricket and percussion recordings. These sounds became key parts of a sound composition. It could be suggested that the playback of a sound in the composition reflects the instrument object's voice as a part in the sound piece.

Video documentation and description of performance

A video excerpt of a performance of this work, from August 2012, can be seen at the following link: **https://vimeo.com/55188608**. This file is also provided with a copy of this PDF entitled 'ZBacchus_hearingWhatWeSeeVideo'.

I found that the best way to incorporate the device was to fit the camera directly onto a pair of glasses, however, these glasses needed to be tied on to my head and held in an upright manner because the position of the camera relative to the moving eye needed to be rigidly fixed and also because they could fall off or be nudged too far from an optimal tracking position on the face. For this reason, my body movements were restricted and extensive practice was required to create narrative body movements that did not interfere with wearing the glasses These restrictions of wearing the eye tracking instrument were used to guide my movement and the act of looking in the persona in a most interesting manner, as if I was guided by my eyes and as if the head and glasses apparatus were a new commanding extension of the body.

While considering my past training and study in body movement, I intended that during the performance my movements would be activated without conscious effort other than to move with looking in two ways. The first way was to simply 'look' at the people in the room as if seeing them for the first time, and the other way was to 'look' in order to navigate the path through the performance space in a constant and slow manner.

The video shows the slow movement of my body through the performance space and the audience. During the performance the accompanying music was composed to guide my movement at a steady tempo and this helped to create an intensity of the activity of looking for the audience members. The glasses were constructed so that my left eye was only partially hidden by the tracking camera, and my right eye was completely visible through the wooden frame. As I looked at the spectators I tried not to direct my eyes to change the sound and to achieve a sort of dialogue with the eyes between the spectators, the environment and myself. Most of the people I looked at smiled or giggled in a disconcerted manner when they stared back at me. This was to be expected, because the costume was eerie and white, and for most people, it generally feels uncomfortable to be stared at. However, during this dialogue, other spectators could watch and listen to this performance and experience from a different point of view the sound of my looking at others and the environment. Similar to the audio recording from the preliminary sound testing set up with the eye-tracking instrument 'eyeTrackerWithCricket.WAV', one can observe the changing sound of the cricket loop in the sound track of the video documentation of the performance. This sound increases and decreases in frequency and duration as it is modulated by my moving eye in the act of my looking.

Figure 6. Screen captures of video documentation for looking performance using the eye-tracking glasses.


Discussion

The art research project presented in this thesis is an important tool for defining new and existing applications of using eye-tracking technology. This project sought to create sights for the ear by re-associating the activity of looking into sound. With the aid of a low cost eye tracking system, a visual sound instrument was built and embedded into the structure of a performance.

During the performance, listeners can observe visual sounds by the characteristics of the changing playback speed of the sound loops. The varying sounds are significant in the performance because they are linked to the changing movement of the centre point of the eye and the increasing and decreasing frequency and duration of the playback of sounds changed with the eye's movement toward a point of interest. But identifying the sound in the performance is abstract for the spectator and the user without a full understanding of the instrument and its voice. The gaze could be identified by an extended and repeated frequency pattern of the sound clip being projected. Once the link between the eye's movement and the changing sounds are explained to the spectators this pattern could be recognized in the soundscape of the performance.

Stephen Handel (1991) links the qualities of the sound to an instrument and also its unique noise. In his guide to sound perception, he provides examples "such as the breathy sound of a flute" (p. 169) to indicate the unique associative nature of our ability to understand the affordance described here in this type of sound. Handel (1991) brings to light the fact that prior experience plays a role in the sound characterizations we come to understand. We would most likely not be able to identify a flute being played in an audio recording if we had never experienced it before. The performer brings to this process the expression of something of interest relative to the sound being transmitted, where the visual sounds emitted by the instrument are the eye movements that physically control the parameters of sound, such as the frequency and duration of the looped playback of a single cricket chirp and a percussive hit. In this way, sound changes occur in the performance relative to the position of the eye within the limits of its field of movement. Because this performance utilized a "new" instrument for making sound, it was not expected that the spectators would immediately recognize the visual sounds. However, this dilemma can be quickly resolved when a technical explanation of the work's apparatus and tracking methods are described, but it is difficult to decide if explaining unknown sounds could be more interesting for a keen listener. Perhaps there would be too much focus on the mechanics of the instrument rather than the aesthetics of the performance if the technical set up of the eye-tracking instrument is fully explained before a performance. I am undecided wether to reveal and explain before or after the performance the true nature of the visual sounds.

But how can the characteristic of the visual sounds in the performance be related to a person's Theory of Mind? It is the activity of looking that can be heard as I follow the processes of the movement dictated by my thoughts. The instrument enabled the control of sound with the visual movements to allow us to listen in to the needs and interests of the 'looker' seeking visual information in the ongoing world.

This thesis project suggests a method for creating a work of art that uses an eye-tracking device as an instrument. The instrument is a part of the artwork's impression because it provides sensory observations and insight, expresses visual sounds, and can perform consistently. Within this artwork we can observe the operation of one of our sensory systems, looking, by hearing the changes in the sound. In this manner, the instrument will have done what it was supposed to do: transform the movement of the looking eye into sound. The observation of the sounds, the meaning associated with the rate and duration of the sounds, the number of times they hear the visual sounds in a composition, and the subtle variations that they bring with their experience is up to the spectator and their own perceptions.

This thesis research seeks to find creative ways of using technology for my artistic performances using "do it yourself – DIY" techniques. DIY is a useful way to combine sensory technologies with intuition. An interview with Vancouver artist Thecla Schiphorst (bodydataspace, 2011) states: "the really important thing that we need are people who can think into the future… that can think of how we use what is possible now to create what people haven't thought of yet." Overall, this interview suggests that to keep up with the changing needs and technologies of the world, expressive devices require constant innovation. In this thesis, I used DIY techniques for modifying a small camera and constructing an eye tracking instrument that follows the moving position of the eye so that I could use this changing movement data to make changing sounds. This technique allowed for individual experimentation at a low cost so that multiple eye tracking prototypes could be built toward designing the most suitable interface for a performance. The result was a set of eye tracking glasses that could capture the movement of the eye in real-time, during the performance of the final artwork.

Future directions for incorporating eye tracking in art works would be to expand a participatory device that enables the spectator to become more involved in the work. At this time, the technology available permits the use of consistent eye tracking in artworks in a limited capacity, where the head of the user must be rigidly fixated for the tracking procedure. This process is difficult and time consuming for any novice. In terms of the wearable eye tracking glasses for performances, better computer programming with a better resolution camera could be investigated more fully, for a higher quality design and data output of the tracking instrument. An achievement for this project was to use low cost, readily available technologies that could be easily incorporated into a project to investigate the possible application of eye tracking in performance. The video documentation of the performance shows I was able to combine the restriction of my movements (due to the fragility of the glasses) in the space with a simplified and expressive act of looking. I found that to achieve this combination, it was necessary to let go of any prior expectations during my act of looking. I believe that during the live performance, spectators showed an interest in connecting the output of the sounds to the movements of my eyes by the way that they gathered around my body to inspect my actions and listen to this performance piece. After the performance, some of the audience members were keen to discuss the connection between the instrument and the sounds that they heard as they were shown how the eye tracking glasses output sounds modulated by my moving eye on the computer screen. Perhaps in future performances, it would be more helpful if this explanation could be done prior to the performance using a written description in the program of the event.

In the performance, I was able to move my eyes and consciously look at the people and the environment as a dialogue expressed with the eyes. In the next phase of performing with this research tool, and with more available resources, wireless technology should be incorporated into this device so that the available performance area can be expanded without restricting the interaction between the performer and the audience. A wireless connection between the glasses and the computer will allow for a more liberated expression of the persona without thinking about the technology while performing. In this way it is now possible to consider expanding and fine-tuning the eye tracking instrument as a valid performance tool, now that this artwork's first performance is completed.

References

Barthes, R. (1985). Listening. In R. Barthes, *The Responsibilty of Forms – Critical Essays on Music, Art and Representation. Trans. Richard Howard* (pp. 245-260). New York, NY: Hill & Wang, 1985.

Bijsterveld, K. (2008). *Mechanical Sound-Technology, Culture and Public Problems of Noise in the 20th Century*. Cambridge, MA: MIT Press.

Blake, R., & Sekuler, R. (2005). *Perception* (5^{th} ed.). New York, NY: McGraw Hill.

Bodydataspace. (2011). *Robots and Avatars Vodcast #4*. Retrieved September 1, 2011 from http://www.youtube.com/watch?v=nfLRZC3AeVE

Bregman, A. S. (1990). *Auditory scene analysis: the perceptual organisation of sound*. Cambridge, MA: MIT Press.

Gagnon, J. (2000). *Lynn Hershman, Room of One's Own*. Retrieved September 1, 2011 from: http://www.fondation-langlois.org/html/e/page.php?NumPage=169

Glucksberg, S. & Rubio-Fernandez, P. (2011). Reasoning About Other People's Beliefs: Bilinguals Have an Advantage. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38 (1),* 211–217.

Griffiths, C. (2003). Articulated Space. *Le son dans l'art contemporain canadien / Sound in Contemporary Canadian Art, sous la direction de Nicole Gingras. Editions Artextes, Montréal, 2003*, 106-113.

Handel, S. (1991). *Listening: An Introduction to the Perception of Auditory Events*. Chapter 6. Cambridge, MA: MIT Press.

Hartman, C. (2009). *Talking Glove Speaks For The Deaf*. Retrieved June 1, 2012 from: http://www.cbsnews.com/2100-205_162-566431.html

Hayhoe, M. & Ballard, D. (2005). Eye movements in natural behaviour. *Trends in Cognitive Sciences, 9(4),* 188-194.

Jensenius, A., Wanderley, M., Godoy, R., & Leman, M. (2010). Musical Gestures: Concepts and Methods in Research. In R. Godoy & M. Leman, M. (Eds.), *Musical Gestures, Sound, Movement and Meaning,* 12 – 35. New York, NY: Routledge.

Johnson, A. & Gurnsey, R. (2010). Size scaling compensates for sensitivity loss produced by a simulated central scotoma in a shape-from-texture task. *Journal of Vision 10(12):18*, 1-16.

Kaulard, K., Tatler, B. & Wade, N. (2007). Examining art: dissociating pattern and perceptual influences on oculomotor behaviour. *Spatial Vision, 21(1-2),* 165-184.

Koch, C. & Ullman, S. (1985). Shifts in selective visual attention: towards underlying neural circuitry. *Human Neurobiology, 4*. 219-227.

Knudsen, E. (2007). Fundamental components of Attention. *Annual Review of Neuroscience, 30*. 57-78.

Land, M. (2009). Vision, eye movements, and natural behavior. *Visual Neuroscience (26), 51-62*.

Lee, S. (2011). *Hi tech specs give game developers insight into what players really see*. Retrieved July 8 from: http://www.gamasutra.com/view/pressreleases/73568/Hi_tech_specs_give_game_developers_insight_into_what_playersreally_see.php

Llinás, R. (2001). I of the vortex. Cambridge, Massachusetts: MIT Press.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264*, 746-748.

Nandan, A. (2009). Eye Movements or Drishthi Bheda. In *Online Bharatanatyam*. Retrieved June 2012 from: http://onlinebharatanatyam.com/2010/06/eye-movements-or-drishthi-bheda/

Nancy, J. (2007). *Listening*. New York, NY: Fordham University Press.

Nielsen, J. (2009). *Eyetracking Research: Findings from Nielsen Norman Group's usability studies using eye tracking technology*. Retrieved July 8, 2012 from: http://www.useit.com/eyetracking/

Pasquero, J. (2009). *Survey on Communication through Touch*. Retrieved August 14, 2012 from: http://www.cim.mcgill.ca/~haptic/pub/JP-CIM-TR-06.pdf

Polli, A. (2001). *Intuitive Ocusonics: Eye Tracking Musical Instrument Interfaces*. Retreived September 1, 2011 from: http://www.andreapolli.com/

Rayner, K. (1998). Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological Bulletin, 124(3),* 372-422.

Rokeby, David. (1990). The very nervous system. Retrieved March 11, 2013 from: http://www.davidrokeby.com/vns.html

Sanders, R. (2012). *Scientists decode brain waves to eavesdrop on what we hear*. Retrieved June 1, 2012 from: http://newscenter.berkeley.edu/2012/01/31/scientists-decode-brain-waves-to-eavesdrop-on-what-we-hear/

Saunders, D., Williamson, D., & Troje, N. (2010). Gaze patterns during perception of direction and gender from biological motion. *Journal of Vision*. 10(11):9, 1-10.

Seeing Machines. (2012). Retrieved June 1, 2012 from: http://www.seeingmachines.com/.

Tatler, B. (2009). Current understanding of eye guidance. *Visual Cognition, 17(6),* 777-789.

Tatler, B. & Vincent, B. (2009). The prominence of behavioural biases in eye guidance. *Psychology Press, 17(6/7),* 1029-1054.

The cocktail party effect. (2012). In *Encyclopædia Britannica*. Retrieved August 1, 2012 from http://0-www.britannica.com.mercury.concordia.ca/EBchecked/topic/123736/cocktail-party-effect

The EyeWriter (n.d.). [website] Retrieved August 2010, from: http://fffff.at/eyewriter/

Tolstoy, L. (1904). *What Is Art?* Chapter 5. New York: Funk & Wagnalls Company. Retrieved October, 2012 from: http://archive.org/stream/whatisart00tolsuoft#page/46/mode/2up

Varese, E., & Wen-chung, C. (1966). The Liberation of Sound. *Perspectives of New Music, 5(1)*, 11-19. Retrieved March2012 from: http://music.arts.uci.edu/dobrian/CMC2009/Liberation.pdf

Wooding, D. (2002). Fixation Maps: Quanitifying Eye Movements. *ETRA '02 Proceedings of the 2002 symposium on Eye tracking research & applications*, *31-36*. Retreived March 2013 from: http://csi.ufs.ac.za/resres/files/Wooding.pdf

Yarbus, A. (1967). Eye Movements and Vision. New York, NY: Plenum Press.

Appendix 1.

To explore the design of the instrument, several prototypes were made and ranged from hand held to standing devices. Figure 7 shows a series of images documenting the construction of the apparatus up to the final performing mask.

Figure 7. Images of the instrument prototypes

Figure 7 shows images of instruments built in the prototyping process. These instruments include a hand-held box, a standing mask and wearable eye tracking glasses. The standing eye tracking instrument was difficult for novice players to use and it was found that an intensive introductory session was required to explain to each participant where to place the face in the optimal position relative to the eye piece so that both the tracking camera could be in front of the eye and so that the user could still see beyond the apparatus to images in the viewing scene. These prototypes helped to establish the glasses as the final performance instrument in this thesis project.