OVERCOMING THE VISUAL BARRIER: ENHANCING CLASSICAL MUSIC ACCESSIBILITY THROUGH ALTERNATIVE SIGHT-READING METHODS

by

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Within western practices, music is typically learned either by sight or by ear. Sight-reading, a skill that relies on processing visual information from musical notation and immediately translating it into playing an instrument or singing, has long been considered a fundamental measure of classical musical ability. However, visually impaired individuals face significant challenges in compensating for their lack of sight, making sight-reading an extremely difficult task. Existing adaptive alternatives, such as braille music or 3D printed music, have limitations in terms of cost and the inability to read and play simultaneously. Research has shown that blind individuals compensate for their visual impairment by enhancing their other senses. They have been found to possess a heightened sensitivity to discrimination of music stimuli, as well as the sense of touch. This enhanced tactile sensitivity is likely a result of cross-modal plasticity, where the brain's visual areas adapt to the absence of visual input and repurpose tactile processing areas. Drawing from this knowledge, I have developed a proposed process aimed at simulating sight-reading for the blind. Leveraging vibrotactile systems, which are commonly found in haptic feedback technologies such as smartphones or video

game controllers, involves stimulating tiny nodes attached to the body's surface to represent musical notes, such as the keys on a piano. The goal is to enable blind individuals to perform at a similar, or even higher level, than traditional sight-reading. By utilizing vibrotactile systems and taking advantage of the heightened tactile sensitivity of blind individuals, this proposed system holds promise for making classical music more accessible to the visually impaired.

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ACKNOWLEDGMENTS

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KEY TERMS

***A note on terminology when referring to a blind individual:** According to the National Center on Disability and Journalism, referring to someone as a "blind individual" is generally accepted when the person has a complete lack of sight (Silverman, 2021). The journals mentioned in this thesis use similar language.

Acuity (tactile and auditory): Keenness or sharpness of the senses (touch and hearing).

Broca's area: A region of the left frontal lobe of the brain associated with the production of language.

Classical music: Music written in the western tradition (Oxford Dictionary, 2023).

Cross-modal plasticity: When one region of the brain is deprived of its typical sensory modality, and causes the anatomical restructuring of the brain pathways, remapping these brain functions. This leads to heightened sensory areas to compensate for their lost sensory modality, e.g., the lack of the stimulus of the sense of sight resulting in higher sensitivity in the sense of touch.

Fronto-temporal (region of the brain): Associated with personality, behavior, and language.

Functional connectivity: The statistical dependencies or correlations between the activities of different brain regions, as measured by neuroimaging techniques, and how different regions of the brain communicate and work together to perform various cognitive functions.

Motor output: The brain receives input and sends movement to glands or muscles, producing movement.

Physiology (physiological): How living organisms function.

Proprioception: Awareness of the body in space, often guided by the sense of touch.

Sight-reading: The ability to simultaneously read music and play/sing the music without seeing it prior.

Vibrotactile Systems: Assistive devices that transform visual information into tactile or vibratory sensations.

3-DMR task: Sluming et al., 2007, utilizes a task in which three-dimensional perspective drawings are given in different orientations, and the subject must visualize/mentally rotate the one object to match it with its appropriate rotated counterpart.

INTRODUCTION

Within the western practices of music, there are two standardized methods one can employ to learn music: aurally and visually. Learning through visual means relies on the ability for one to process visual information from musical notation, and relay it into musical production. Learning aurally, or “by ear,” involves a player’s ability to process the auditory stimulation of music and match the musical pitch, volume, rhythm, and distinct punctuation.

The sense of sight is required to demonstrate musical comprehension at an institutional level. Learning music incorporates the process of sight-reading, or the ability to simultaneously read music and play/sing the music without seeing it before. This skill is often utilized as an assessment of musical ability, and is common in the audition process for professional orchestras or musical institutions. For an individual who is blind, limited alternatives exist to the standard notation of sheet music. Current substitutes include braille music, or 3-D printed music, but both of these have their own challenges of cost and expertise to code the printing itself.

In this thesis, a thorough review of the present literature on the physiological aspects of music in visually-impaired individuals in comparison to sighted individuals will be investigated. The outcome will shed light on the gaps of this topic within the scientific community, and highlight the importance of inclusion and accessibility in the musical community. Utilizing the proposed methods at the end of this document, it is hoped that further research can be conducted to give access to alternate means of sight-reading through the use of vibrotactile feedback.

Research Question: What method would allow a blind individual to learn music in a way that is similar to traditional sight-reading?

LITERATURE REVIEW

Standard practices of learning music

The two modalities to learn music are by ear and by sight. These methodologies of learning music have divided the music community between classical, and genres that rely on improvisation, such as jazz. This divide stems back to the roots of classical music in Europe, in which learning to play an instrument or sing was considered a sign of wealth. Even in our present day, learning classical music is a sign of wealth and education, with average music lessons ranging from $64-90 an hour (Ensemble Schools, 2023). This does not take in consideration the prices of obtaining an instrument alone. Improvisational modalities of music stem from cultures such as the American South, in which the intersectionality of several cultures created a new form of music (Benedek et al., 2013). It should be noted that improvisational methods of learning music characteristically allows for more inclusion for musicians with disabilities.

Importance of music for blind individuals

It has been suggested that every individual exhibits an innate interest in music from early life (Malloch, 1993). For a person with visual disabilities, this type of art form becomes highly important. Thanks to the inherent auditory aspect of music, it is a very easily accessible and communicative type of art. The perception of music is direct, without the involvement of the sense of sight, smell or taste. A blind or partially-sighted person who does not suffer any difficulties or limitations when listening, reproducing, or creating music could hypothetically perform at the same level as sighted individuals.

Thus, it is important that music is an accessible art form for those who are visually impaired, regardless of the genre.

What is sight-reading?

Sight-reading describes the process of reading music and simultaneously singing/playing it on an instrument immediately after it is viewed. This is a skill that has been a solidified measure of one's classical musical ability, and is commonplace in testing for musicians of all age ranges. Sight-reading involves processing written notations of music, then immediately converting these interpretations into motor output (Bortz et al., 2018). This skill is also characterized by the capacity for a performer to process this complex visual stimulus under time constraints, and with little to no opportunity to correct their errors (Kopiez et al., 2006). Studies of ocular movement have found that reading music involves more multidirectional movement than reading alphabetized text (Udtaisuk, 2005). For example, musical scores for piano are presented on two staves (for the left and right hands). The staves are oriented one above the other, showing all the notes to be played simultaneously by both hands. When pianists advance through musical notation, their eye movements must alternate between these two staves (Dormehl, 2017; Udtaisuk, 2005; Furneaux & Land, 1999).

Sight-reading is a highly important factor in the ability for a musician to perform a piece of rehearsed music. This involves the transformational sensorimotor skill of positioning the fingers at the appropriate space on an instrument at the precise, correct moment. Reading music in general is a visuospatial task, where information conveyed by spatial location and the vertical orientation of notes are directly related to musical intervals (Sluming et al., 2007). This differs from the task of reading printed alphabetic text (Sergent et al., 1992). To be a highly skilled sight reader would constitute the ability to transform written musical notation into the motor action of musical performance at incredibly high speeds.

Alternative means for sheet music for the visually impaired

For someone who is visually impaired, this concept of sight-reading is a nearly impossible task. There are other means for reading sheet music that have been adapted by this community. The most common modality is through braille music (see Figure 1). This, however, is limited in its translation of certain musical notation. Braille music cannot translate detailed notations of volume control or musical punctuation (Bouabid, 2013).

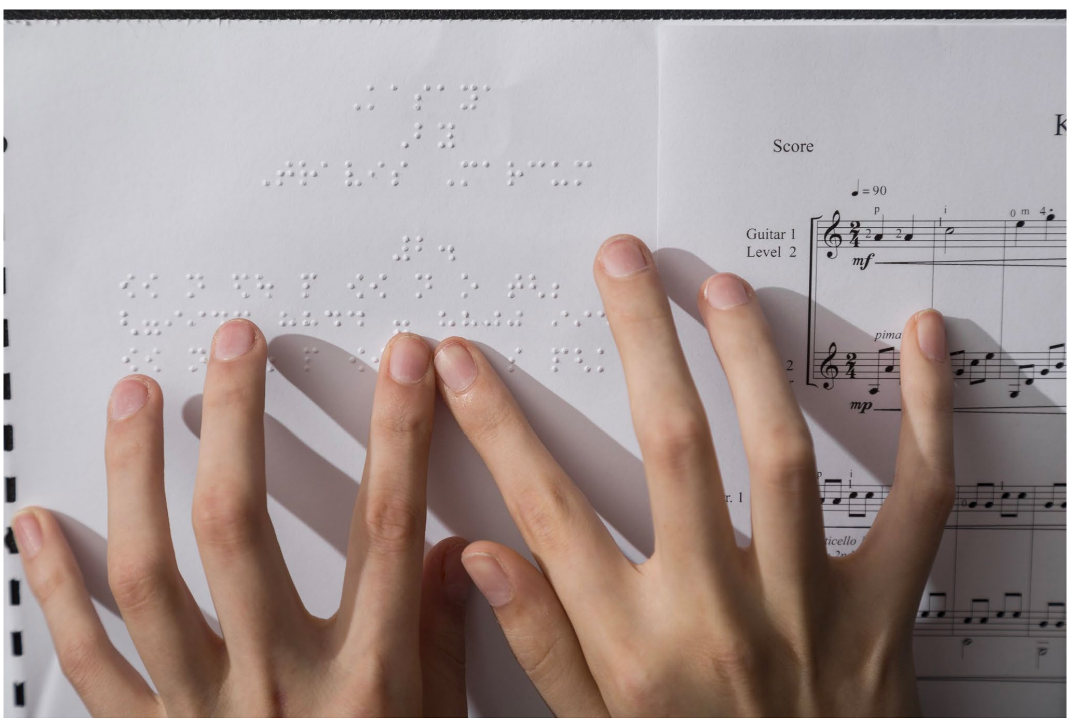

Figure 1: An example of braille printed sheet music (left) compared to traditional sheet (right).

A recent development has been that of Yeaji Kim's, a Doctor of Musical Arts from the University of Wisconsin-Madison. She has developed a Tactile Stave Notation (see Figure 2), in which the entire written portion of a traditional piece of sheet music is 3-D printed (Worland, 2014). This notation allows for the translation of all of the information presented in a standardized sheet of music. However, both of these alternatives suffer from the same limitations. The first is cost and accessibility- both of these methods can become expensive. These also require someone with both vision and the ability to print 3-D music.

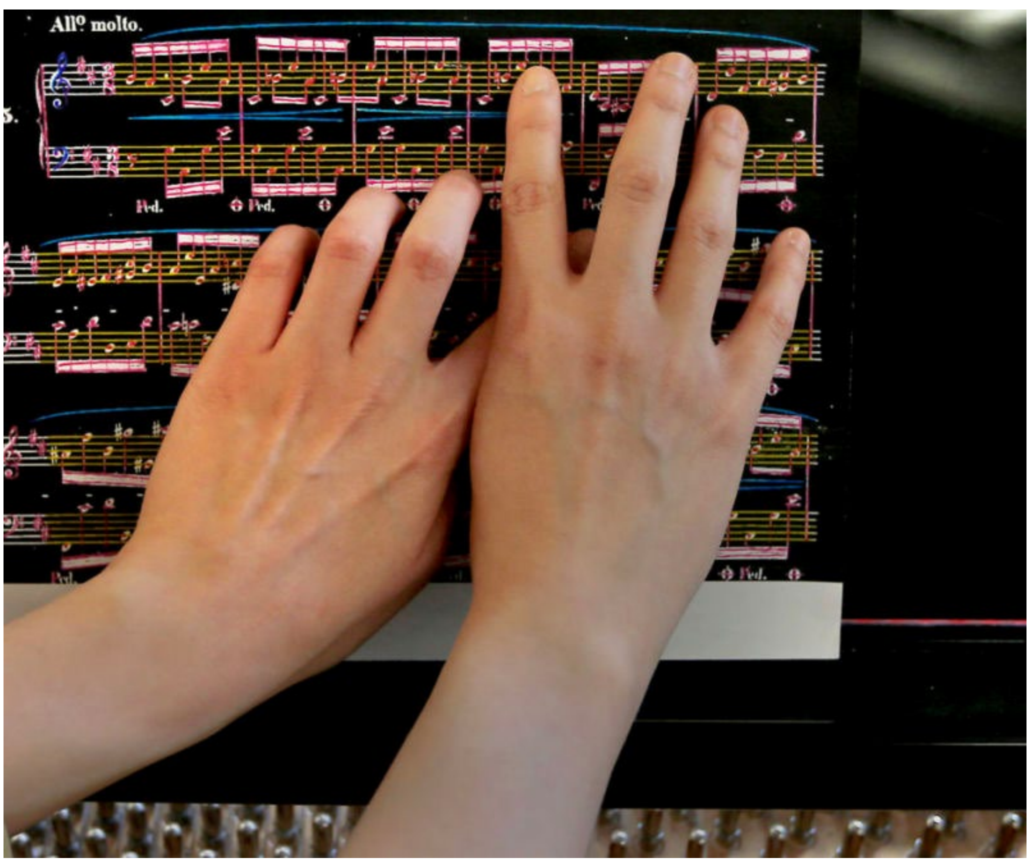

Figure 2: An example of tactile stave notation, allowing a player to feel the entire written portion of sheet music through their fingertips.

Alongside this, the process of “true” sight-reading is a nearly impossible task utilizing braille music or 3-D printed music as these mediums do not allow for the simultaneous interpretation of the musical notation and translating that into sound (Bouabid, 2013). There have been no such means of accomplishing this task.

For someone with hearing impairments, the modalities of sheet music are already in place for someone to learn music without the sense of sound. The limitations of this, as expected, are relying on vibrations and the response of listeners for accuracy of note-playing, and the volume of sound produced by the musician. This method of learning music is not widely accepted within the classical music field (Gordon, 1997).

Blind individuals, and skill acquisition

Those who are blind have been found to compensate for their lack of vision by heightening their other working senses (Morin-Parent et al., 2017). Studies have found that blind individuals modify their skill acquisition, and thus alter their motor learning. Language processing involves a left-lateralized series of frontotemporal cortical regions of the brain. Through a series of experiments and reports conducted in 2016, it has been found that blind individuals have less of a left-lateralized network for processing language in comparison to sighted individuals. It has also been seen that this network spans over to the right side of the brain for blind individuals (Lane et al., 2016). It was also demonstrated that blind individuals have a lower threshold for discrimination compared to the sighted individuals for vowels, music stimuli, and pure tones (Arnaud et al., 2018).

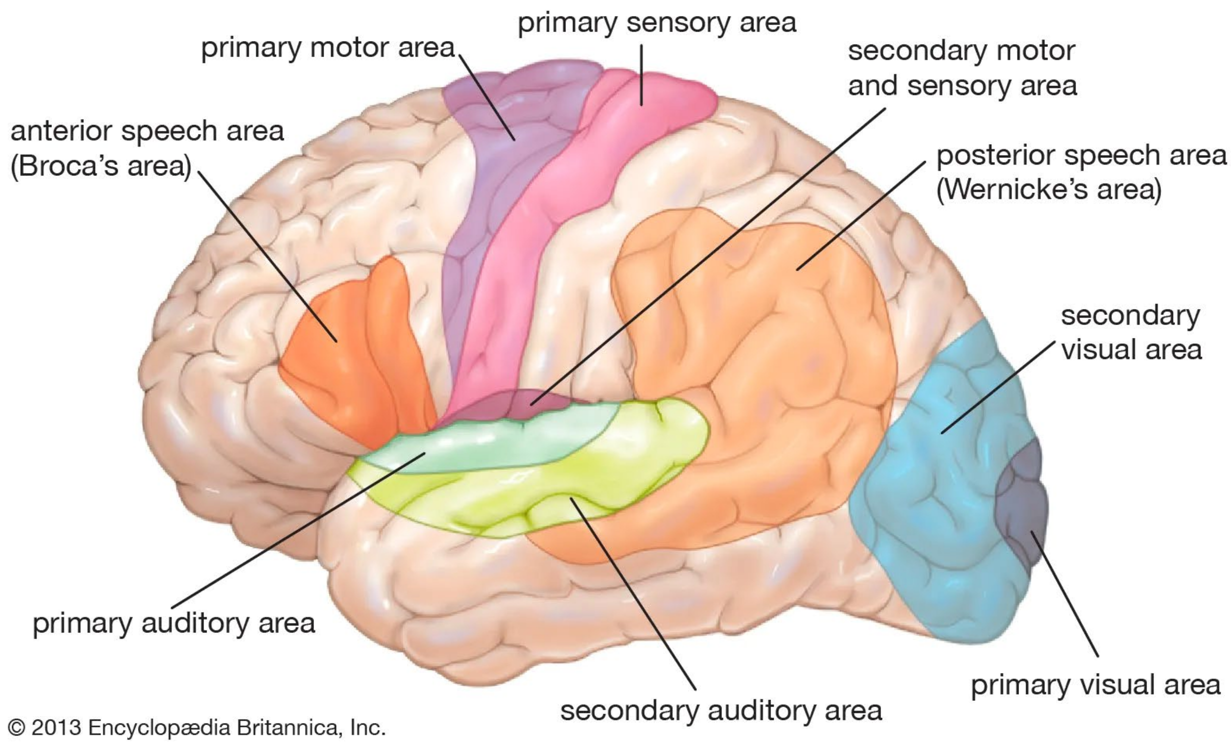

Figure 3: Functional areas of the brain, notably the Broca's area, visual areas, and auditory areas.

Tactile acuity

There are two contrasting hypotheses aimed at explaining the increased tactile acuity observed in blind individuals: the tactile experience hypothesis proposes that active engagement with touch enhances their tactile acuity, while the visual deprivation hypothesis suggests that the absence of sight itself contributes to improved tactile acuity.

In a study conducted in 2011, researchers investigated the tactile acuity of both blind and sighted individuals using force-grating orientation tasks. This involved a "finger testing" procedure where participants applied a specific force to their fingertip placed on a rod with patterned gratings. The study's findings provided support for the tactile experience hypothesis. Both blind individuals who read braille and blind individuals who do not read braille outperformed sighted individuals in braille reading tasks. These results indicate that the heightened tactile abilities in blind individuals are primarily driven by their extensive tactile experience (Wong et al., 2011).

It's worth noting that blind individuals heavily rely on tactile information due to cross-modal plasticity, a phenomenon where the occipital cortical areas, normally responsible for processing visual input, adapt to process tactile information in the absence of typical visual input. However, the results of this study suggest that the improved tactile acuity in blind individuals is primarily a result of their tactile experience rather than solely being attributed to visual deprivation (Wong et al., 2011).

Blind musicians who read braille music rely heavily on their sense of touch to read and interpret musical scores. Braille music notation utilizes raised dots and symbols to represent musical notes. To read braille music, blind musicians use their fingers to trace the raised dots, which requires a high degree of tactile sensitivity and discrimination (Mašić, 2020).

BOLD signals, a type of functional magnetic resonance imaging (fMRI), which detects changes in cortical blood flow, blood oxygenation, and blood metabolism, have been utilized to assess blind individuals' tactile acuity. It has been shown that blind individuals have increased functional connectivity in the somatosensory cortex, which is responsible for processing tactile information (Mašić al., 2020). Furthermore, studies have shown that blind individuals have improved connectivity between the somatosensory and auditory cortex (see Figure 3), which may facilitate cross-modal processing of sensory information (Teichert & Bolz, 2018).

Auditory spatialization

In addition to their increased tactile abilities, blind musicians also exhibit enhanced auditory acuity and spatial representation. Blind individuals have been shown to have superior pitch discrimination and the ability to detect subtle changes in timbre and tone compared to sighted individuals (Gougoux et al., 2004). Furthermore, studies have shown that blind individuals have improved spatial memory and spatial cognition as compared to sighted individuals, which may be due to their reliance on spatial auditory cues (Lessard et al., 1998).

A study conducted in 1998 by Lessard et al., shed light on the enhanced auditory spatial abilities of early-blind individuals compared to sighted or partially-blind individuals. Early-blind subjects tested under both monaural (one ear) and binaural (both ears) conditions demonstrated superior auditory spatial mapping and accuracy. In addition, early-blind individuals possess the ability to localize sounds using only one ear (monaural localization), which is a remarkable skill. This finding suggests that the absence of sight from an early age prompts compensatory adaptations in the auditory system, enabling blind individuals to rely more heavily on auditory cues for spatial information (Lessard et al., 1998).

Interestingly, the study also revealed that partially blind individuals encounter more difficulties in localizing sounds compared to both totally-blind and sighted individuals. This could be attributed to the fact that partially blind individuals still rely on visual input to some extent, which might interfere with their ability to fully develop and utilize auditory spatial mapping skills to the extent that fully-blind individuals do (Lessard et al., 1998).

When considering the connection to sight reading for the blind, these findings highlight the adaptive nature of blind individuals' sensory abilities. Since blind individuals cannot rely on visual cues to access written information, they heavily utilize alternative modalities, such as touch or auditory cues for reading. The heightened auditory spatial abilities observed in blind individuals could potentially aid them in tasks such as locating auditory cues, facilitating their engagement with the auditory aspect of written musical material despite the absence of sight.

Broca's area

Plasticity is not limited to the somatosensory and auditory cortex. Studies have also shown that blind individuals have an increased functional connectivity between Broca's area, a region of the brain that is important for language production, and the thalamus, supramarginal gyrus, and cerebellum (Heine et al., 2015). This suggests that the visual deprivation experienced by blind individuals can lead to reorganization in language production areas of the brain, which may be related to their enhanced musical abilities.

The Broca's area of the brain is hypothesized to have a larger amount of gray matter in those with classical music training, which would benefit the visuospatial network, and also the sequencing of rapid motor actions. It is also thought that the Broca’s area subserves the neural network of sight-reading (Sluming et al., 2007).

A study conducted in 2007 investigated long-term motor skills in professional orchestra musicians. To test the activation of the Broca’s area, a three-dimensional mental rotation (3-DMR) task was utilized. Subjects were pooled from a professional orchestra, and non-musicians with no musical background. It was found that the process of organizing the motor sequencing to execute an enhanced performance of a 3-DMR task recruits similar brain areas as the visuospatial sight-reading skills of musical performance. Professional orchestra musicians displayed enhanced performance in the visuospatial task of 3-DMR, which corresponded with an increased activation in the Broca’s area (Sluming et al., 2007). It has also been found that music can help with language acquisition; the Broca’s area is used more effectively with the intervention of music (Dastgheib, 2013).

These findings suggest a potential link between the development of motor sequencing skills, supported by the enhanced activation of Broca's area, and the visuospatial demands of sight-reading. It is plausible to speculate that blind musicians, who heavily rely on proprioception and tactile exploration to read and interpret braille music, may engage Broca's area in a similar manner as they mentally sequence and map the spatial information of the music notation.

Therefore, the heightened development of Broca's area in blind individuals may play a role in supporting their sight-reading abilities by facilitating the integration of motor sequencing, language production, and visuospatial skills. This neural network, combined with the enhanced proprioceptive and tactile acuity observed in blind musicians, contributes to their unique ability to engage in classical music.

Understanding the relationship between proprioception, heightened Broca's area, and musical competency in blind individuals provides valuable insights into the complex cognitive processes involved in music perception and performance. It highlights the multifaceted nature of music learning and underscores the potential for leveraging proprioception and neural plasticity to develop accessible sight-reading methods for blind individuals, promoting inclusivity and empowerment in classical music education.

What has not been explored: Vibrotactile systems

While extensive research has investigated the effects of visual deprivation on music learning, there is a significant gap in understanding how utilizing vibrotactile systems through the sense of touch can serve as a substitution for sight-reading.

In recent years, advancements in technology have enabled the development of assistive devices that can convert visual information into tactile or vibratory stimuli. These devices, known as vibrotactile systems, use tactile feedback to convey information to individuals who are visually or auditorily impaired (Wall III, 2010).

Vibrotactile systems have proven to be effective in the effort of inclusion for the blind classical music community. The movements of the orchestra’s baton (ictuses) are what dictate the tempo for the orchestra, and require the sense of sight to be able to follow. A recent development that aids in inclusion for blind orchestra musicians is that of a remote baton that is held by an orchestra conductor. The ictuses of the conductor’s baton are vibrationally stimulated on a player’s leg, signaling the tempo of the piece to follow. This has allowed for the integration of blind classical musicians to play in a hybrid-style orchestra (BBC Stories, 2019).

In contrast to employing vibrotactile systems as a substitution for visual information for rhythm, they could potentially be used in sight-reading. These systems could potentially be designed to represent musical notation through patterns of vibrations or tactile cues on the skin, allowing blind individuals to access musical notation in a more direct and intuitive manner. These systems have the potential to facilitate the translation of visual information into tactile patterns that convey musical symbols, note durations, pitch, dynamics, and other musical elements.

Utilizing vibrotactile cues, blind individuals could explore musical scores, identify the position and duration of notes, and navigate through the music in a tactile manner. The vibratory patterns could represent the spatial layout of notes on a staff, the timing and duration of each note, and even provide feedback on the dynamics and expressive aspects of the music.

While there have been some initial explorations of vibrotactile systems for music learning, further research is needed to evaluate their effectiveness and determine the optimal design parameters. Comparative studies could be conducted to directly compare the efficacy of vibrotactile systems with traditional visual-based sight-reading methods, examining factors such as learning speed, accuracy, and musical expression.

Additionally, it would be important to investigate how training and practice using vibrotactile systems impact the development of music literacy skills in blind individuals. This could include exploring the transferability of skills learned through vibrotactile-based sight-reading to other musical tasks, such as improvisation.

The design of vibrotactile systems should consider individual differences in tactile sensitivity, motor skills, and cognitive processing among blind individuals. Customizable and adaptive approaches could be developed to cater to the specific needs and preferences of different learners.

I have developed the following proposed methods that would utilize a system of vibrotactile stimulation that could rival traditional methods of sight-reading with emphasis on note playing accuracy.

PROPOSED METHODS

Background

In a study conducted in 2018, participants' reaction times (RT) to various conditions of vibrotactile stimulation were investigated. It was found that young adults had faster RTs. Subjects had the fastest RT to 250 Hz of stimulation. Stimulation location at the head had faster RT than stimulation at the peripheral limbs or torso (Bao et al., 2019). It has also been found that the typical RT to a visual response is approximately 180-200 ms (Bao et al., 2019).

Participants

20 young and healthy participants are to be recruited for this study (any gender, ages 18-25). These participants should have no prior experience reading sheet music, or playing any musical instrument, but should express interest in learning. The subject pool is to be randomly sorted into two groups of ten, with each group participating in two separate parts of the study. It should be noted that the sample size is a hypothetical number that would allow for appropriate statistical analysis.

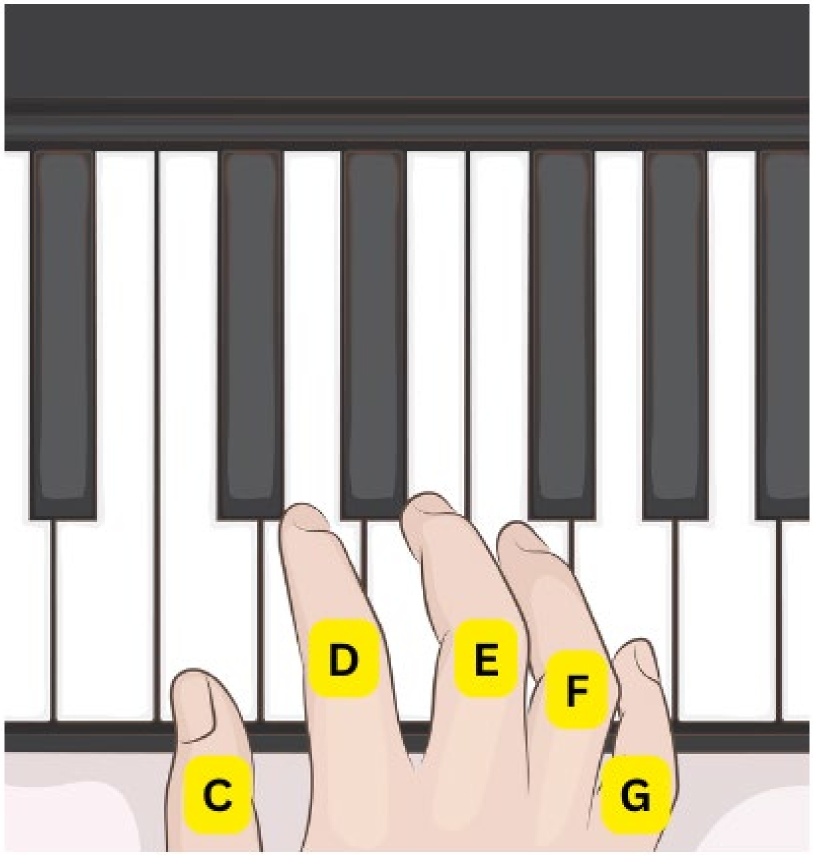

Figure 4: A right hand with the appropriate note names (C-G) that the participant will be tasked to play in both groups.

Group 1, Sighted

This group will be briefed on the note names of a traditional keyboard (utilizing a midi keyboard, notenames C through G). With their dominant hand over the five notes on the keyboard (see Figure 4), they will be tasked with playing randomized strands of music that are 10 notes long (see Figure 5). They will be given the strands of notes one at a time, with written letter names, and can only move on to the next strand when all 10 notes are accurately played. A practice round will be given to allow the participants to familiarize with the interface and keyboard. The keys played will produce the music played in real time. They will preview the notes for 10 seconds before starting each trial without playing any notes; if no playing is detected after 10 seconds, or if they play a note during this preview period, they will be given a different strand, and the trial will be discarded. This preview period simulates the preparation of sight-reading as encouraged by several musical institutions (Wisconsin School Music Association, 2023; Tennessee Tech University, 2023). After the preview period, the note names will be hidden for five seconds. After five seconds, the notes will be revealed again. The participants are encouraged to play these notes as quickly and as accurately as possible (see Figure 6). A successful strand of notes will display a green checkmark and a “correct” chime, while an unsuccessful strand will display a red X-mark and an “incorrect” chime. The study is completed once the subject is able to successfully play three strands of 10 notes without error.

G C F D C E C G F E

Figure 5: An example of the 10-note strand task that the sighted group will be given.

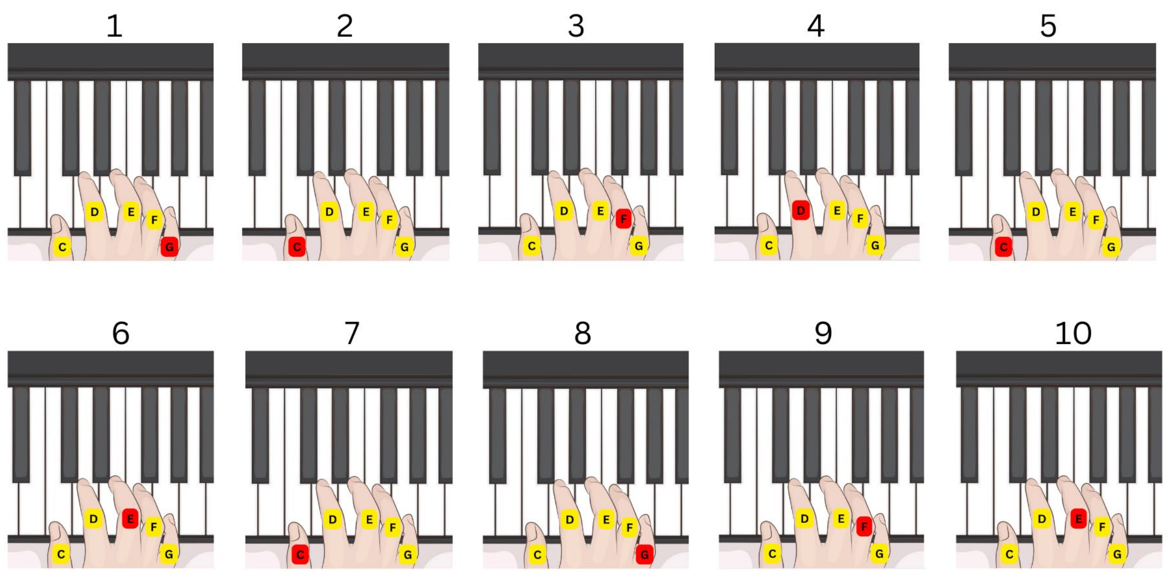

Figure 6: An accurate sequence where a group 1 participant plays the strand of notes (noted 1-10). The note being played is denoted by a red highlight.

Figure 7: A head model with labeled placement of the vibrotactile nodes on a subject's forehead. Starting from the subject's left, they are labeled C-G. Nodes are placed 1 centimeter apart from each other's edges horizontally.

Group 2, Vibrotactiles

This group will be blindfolded and briefed on the keys of the piano. With assistance, they will be guided on where to place their dominant hand on the keys C through G. They are encouraged to play the notes before the trials begin to familiarize themselves with their surroundings, the instrument, and the sounds the keys produce. Five vibrotactile nodes will be placed on the surface of the forehead on the subjects, 1 centimeter apart from the edges of the nodes, with the central node placed centrally on the forehead. Nodes are to be spaced horizontally (see Figure 7). The nodes are to correspond with the notes on the keyboard, with the participant's leftmost node corresponding with the note name C, and the next corresponding with D through G.

Stimulation at 250 Hz will be sent to these nodes. Similar to the sighted-trial, participants will be given a strand of 10 nodes, with stimulation sent to the corresponding note-named nodes on their forehead, at a rate of 1 stimulation per second. Previewing for this trial will be given auditorily, with the strands of 10 notes being played once, then followed by a rest of 10 seconds to allow the participant to visualize and prepare the notes in their head. This will be followed by the vibrotactile stimulation. The participants are encouraged to play the notes directly after each stimulation, as fast as possible. The participants will be given strands of 10 one at a time, until all notes are accurately played (see Figure 6). The keys played will also produce sound in real time. A successful trial without error will produce a “correct” chime, and an unsuccessful trial will produce an “incorrect” chime. The study is completed once the subject is able to successfully play three strands of 10 notes without error.

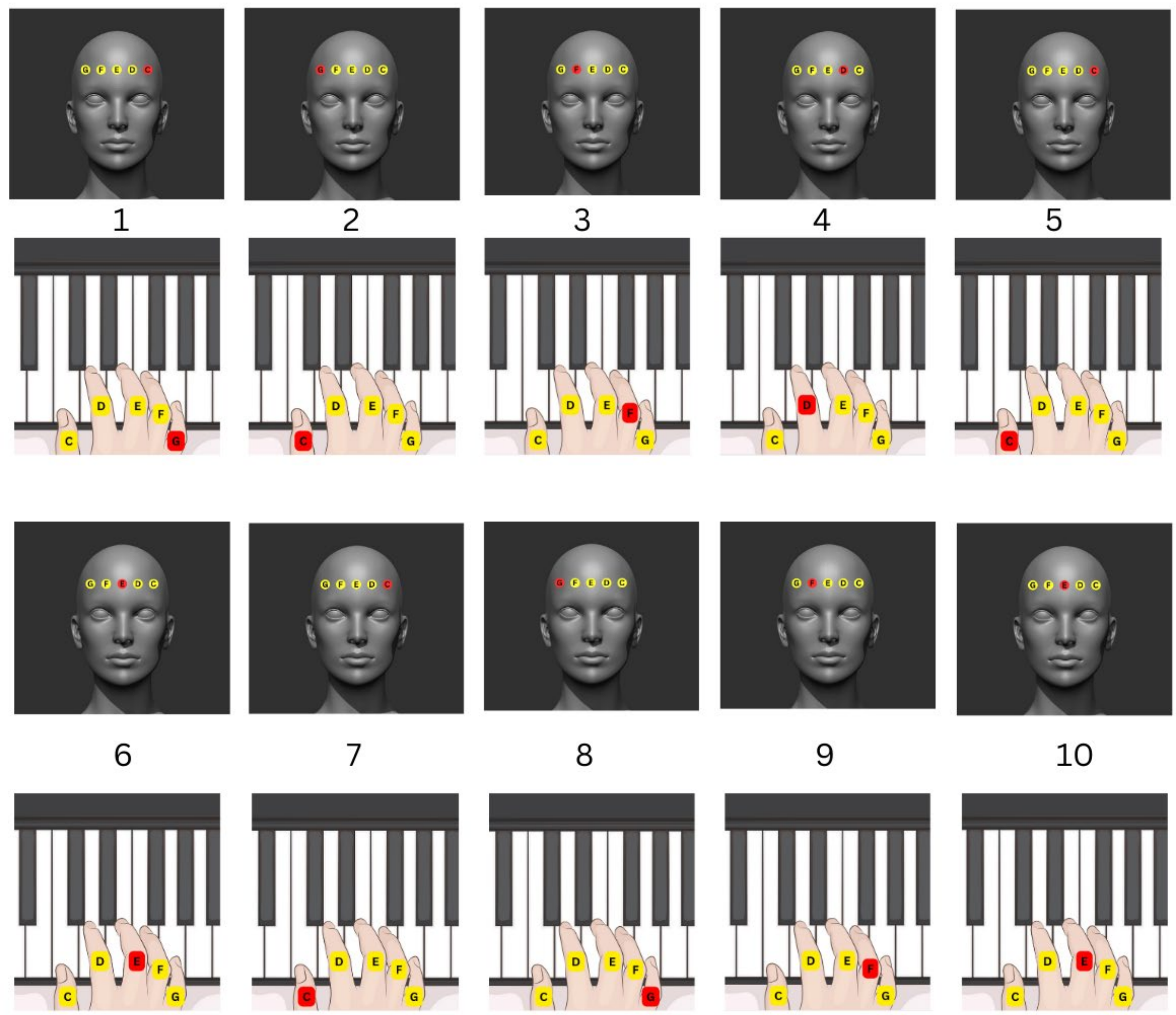

Figure 8: The sequence in which a group 2 participant would complete an accurate strand. Each stimulation (node colored red) corresponds with the playing of its appropriate note (colored red).

Proposed Statistical Analysis

Mean completion time:

The time it takes for each participant to complete three strands of accurate notes will be collected and averaged. Mean completion times for each group will be run under a T-test. P-values < 0.05 will be considered statistically significant.

Latency time:

For the sighted group, the latency between the given strand being revealed and the pressing of the first correct note will be measured and averaged for the three correct strands. For the vibrotactile group, the latency between the first stimulation and the first correct note for the three correct strands will be measured and averaged. A T-test will be conducted between the means of these two groups. P-values of < 0.05 will be considered statistically significant.

Error rates:

For the both groups, the error rate in which each participant incorrectly played a given strand of notes would be collected. This would be calculated as the number of inaccurate strands divided by the total number of strands. This would be calculated as follows:

$$\text{error rate} = X/(X + Y)$$

With X representing inaccurate strands, and Y representing accurate strands.

Retention Time and Learning Curve

To assess retention time and potential learning curve, follow-up assessments will be conducted at specific intervals after the initial completion of the study. These assessments will involve participants from both groups and will follow the same procedures as the initial study. The aim is to evaluate the participants' ability to retain the acquired sight-reading skills and to observe any potential improvement or changes in performance over time.

Limitations

The focus on a specific subset of musical notation, limited to notes C through G, may not capture the full extent of the complexities and variations found in a broader range of musical repertoire. Broader musical context, such as key signatures, time signatures, dynamics, and expressive elements are not assessed in this study. Additionally, the study's termination after participants successfully complete three strands of 10 notes without error introduces a potential ceiling effect, in which some participants may reach successful trials much faster than others. The focus on the piano keyboard limits the generalizability of the findings to other musical instruments.

Although the study's limited musical notation scope and lack of broader musical context may restrict its generalizability, these limitations serve as a starting point for further studies.

CONCLUSION

After conducting a thorough literature review, I have found that there exists very little research in the breadth of adaptive musical technology for those who are fully blind with the concept of sight-reading. Blind individuals have a wide array of neural adaptivity to compensate for their lack of sight. It is interesting to see how an artform like music can utilize neural areas like Broca's area. Within blind-musicians, the integration of their heightened sensitivity to touch in conjunction with increased auditory spatialization could lead to an engagement with vibrotactile systems in a manner similar to that of sight reading.

It is hoped that this proposed methodology could be utilized by myself or another researcher in the near future. A research laboratory like the Action Control Lab at the University of Oregon would provide the necessary expertise to accomplish such a task. It is also hoped that this thesis has provided awareness of the gaps in research and lack of accessibility in the field of classical music. It is hoped that future developments can contribute to the empowerment of the blind community.

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Figures 4, 6, 8: https://www.wikihow.com/Learn-Keyboard-Notes

Figure 7 & 8: https://www.artstation.com/marketplace/p/xb5J/female-head-realistic-base-mesh-3d-model