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Exploration of Sound Design and Sound Representation Techniques for Improving Inclusiveness, Player Performance, and Player Experience in Video Games

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Benjamin Esdor[1]

Figure 1: The player uses a conductor's baton to catch the note (center). The yellow frame around the note letter "E" indicates that the note is to be caught only when the note "E" is played. These instructions are also played back as a voice-over.

This study aimed to explore sound design and sound representation techniques to strengthen the inclusion of players with sensory disabilities alongside non-disabled players. Additionally, it aimed to identify characteristics in inclusiveness components for video games. Tap Tone is a 3D action-adventure prototype with iteratively improved inclusiveness components based on research and requirements analyses. Twenty-five participants were recruited for user tests and divided into four groups: 1) non-disabled, 2) vision impaired, 3) deaf and hard of hearing, and 4) blindfolded players. Data were collected with a questionnaire and saved in-game data. The data was analyzed using statistical methods, including ANOVA and a t-test. Results indicate that the experience for deaf and hard of hearing is significantly different from the groups vision impaired and non-disabled. The results indicate similarities in experience for non-disabled and vision impaired players. Moreover, the player performance indicates similarities between the groups non-disabled, vision impaired and deaf and hard of hearing. Finally, the study identified and discussed key characteristics of the inclusiveness components.

SAMMANFATTNING

Denna studie syftade till att utforska ljuddesign och ljudrepresentationstekniker för att stärka inkluderingen av spelare med sensoriska funktionshinder tillsammans med icke-handikappade spelare. Dessutom syftade det till att identifiera egenskaper i inkluderande komponenter för videospel. Tap Tone är en prototyp av ett 3D-action-äventyrsspel med stegvist förbättrande inkluderingskomponenter baserade på forskning och kravanalyser. Tjugofem deltagare rekryterades för användartester och delades in i fyra grupper: 1) icke-handikappade, 2) synskadade, 3) döva och hörselskadade och 4) spelare med ögonbindel. Data samlades in med ett frågeformulär och data sparad genom spelet. Datan var analyserad med hjälp av statistiska metoder, inklusive ANOVA och ett t-test. Resultaten tyder på att upplevelsen för döva och hörselskadade skiljer sig signifikant från grupperna med synskada och icke-handikappade. Resultaten indikerar likheter i erfarenhet för icke-handikappade och synskadade spelare. Dessutom indikerar spelarens prestation likheter mellan grupperna

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icke-handikappade, synskadade och döva och hörselskadade. Slutligen identifierade och diskuterade studien nyckelegenskaper hos de inkluderande komponenterna.

Keywords: Sound Design, Audio Cues, Video Games, Inclusiveness, Visual Impairment, Deaf and Hard of Hearing

Nyckelord: Ljuddesign, Ljudsignaler, Videospel, Inkludering, Synskadade, Döva och hörselskadade

1 INTRODUCTION

Video games should be accessible to everyone, yet many players face barriers to playing games [4, 6, 14]. Regarding blindness and vision, the WHO reports that at least 2.2 billion people globally have a near or distance vision impairment (VI) [27]. Furthermore, color blindness, low vision, legal blindness, or complete blindness negatively impact player satisfaction and equality with non-disabled players [4, 12, 22]. Research has already identified guidelines and shortcomings in game accessibility [17, 19], and scarce research has discovered that the design and development of auditory components play an increasingly immersive and inclusionary role [19]. Similarly, they found that auditory information, such as music and sound, influences player performance and experience [11].

Various game developers have already started to include interactive sound design techniques for diversity and inclusion or accessibility by design. Sound-driven games like 'Real Sound: Kaze no Regret'[2] or 'Lost and Hound'[3] have contributed to the development of audio orientation cues. For example, the video game publisher Ubisoft has implemented a request from VI players for the game 'Assassin's Creed Valhalla', i.e., audio cues that indicate when the character is stuck [3]. Also, Ubisoft invited Brandon Cole, who is a totally blind gamer, accessibility advocate and accessibility consultant, as a representative for VI players – Cole emphasizes the difficulty of making a game accessible for blind people; for example, each feature in a game must be modified, but overall, they want to play the same games like everyone else is playing [8].

Furthermore, for people who are deaf and hard of hearing (DHH), the WHO reports that globally over 1.5 billion people live with hearing loss [13]. Focusing on visual cues is highly important for DHH and accessibility design still need to be improved as they are often insufficient and not specific enough [9]. For example, Clint Hocking, Creative Director of 'Watch Dogs: Legion' at Ubisoft, describes their development of a visualized sound effects system that captions hundreds of ambient, world, and gameplay sounds [1] to provide gameplay feedback and a sense of the urban soundscape. Another study confirms that sounds can provide information to players [21].

Audio cues are, however, not only beneficial for VI but also for the game performance of sighted players, as the game 'Rocket League'[4] demonstrates: The main game object is a ball controlled by digital cars to achieve goals. Sound designers significantly enhanced the sound of the ball so that players can estimate the trajectory's speed and direction just by hearing the sound [26].

This study focuses on video game sound design to find out: First, how inclusiveness can be strengthened for VI and DHH players by the design of audio orientation cues and sound representation, and second, how these inclusiveness components impact their player performance and experience. This study creates a first-person single-player 3D action-adventure video game for Windows desktop computers called Tap Tone (Figure 1). Tap Tone is a game that strengthens inclusion to connect non-disabled with sensory-disabled players, enabling them to explore a forest environment, discover hidden tones, and collect melodies. The screenshot is from the third prototype.

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[2] https://en.wikipedia.org/wiki/Real_Sound:_Kaze_no_Regret

[3] https://store.steampowered.com/app/1054350/Lost_and_Hound/

[4] https://www.rocketleague.com/

The first objective is to implement inclusiveness components to guide VI players around obstacles solely by sound design. The second objective is to implement sound representation components to avoid dependency on audio cues for DHH players. Observing and interviewing invited study participants and evaluating the gathered data will explore how the enriched audio modality can enhance the players' performance, experience, and inclusiveness.

The study will not provide an all-encompassing game with a sophisticated graphical design but instead will develop a small aspect of a video game idea that is sufficient to evaluate the efficiency of inclusiveness components. Due to the emphasis on sound design, the primary targeted condition is VI. Too, the focus will not be placed on audio games - audio games are defined as a video game with no visual feedback, yet the game will contain graphical elements as one goal is to find techniques to connect non-disabled with sensory-disabled players. The game will also not comply with the *Design for All*[5] approach as individual adaptations are provided for people with disabilities.

In the following, the author will start with the investigation of related work in video game accessibility and subsequently the development of the first prototype. Afterward, requirements will be analyzed in one-on-one interviews with impaired individuals to let their input flow into the early development phase – which will result in the second prototype. The second prototype will be used to conduct a pre-study with three participants, testing the preliminary run of the main study. Based on the results, the third prototype is then developed and followed by the main study. Finally, the results will be recorded and discussed, and the study will be concluded with limitations and an incentive for further research.

2 RELATED WORK

The following section describes the previous findings of the study modules. First, inclusion in video games is clarified, followed by solutions for VI and DHH players, also addressing the impact on player experience, performance, and sound design - leading to the research questions and hypotheses.

2.1 Inclusiveness in Video Games

Progress for accessibility has been achieved in recent years but is still trailing behind in mainstream video games, so people with disabilities are often left unable to play the games and are excluded from social benefits, explains [2], who have performed a systematic literature review in this subject. Following their taxonomy, they divide disability into cognitive, motor, and sensory disabilities. Hereafter, the focus is put on sensory disability, which entails visual disability (e.g., blindness, low vision, or color blindness) and auditory disability (e.g., deafness or hearing loss), meaning players cannot capture certain stimuli. Their review concludes with three main findings: First, custom developed interfaces could lead to a lack of quality and therefore exclude disabled players. Second, third-party technologies prevent inclusion as they might not be customizable, and third, guidelines, techniques, or strategies often need to be addressed by many developers. The last item can be counter-steered by teaching developers these techniques early in their careers. Hence, these techniques and characteristics will be essential in the later part of this study, whereby now the basic framework is set about inclusiveness for VI and DHH players.

2.1.1 Solutions for Vision Impairment

Researchers often examine the impact of low vision or blindness by focusing on audio games. That is no surprise; audio games are based on audio cues and designed to meet the requirements of people with visual impairment. The authors [22] repeat: "*By modifying sound characteristics such as frequency, amplitude, and length or by using the Head-Related*

[5] https://en.wikipedia.org/wiki/Design_for_All_(in_ICT)

Transfer Function (HRTF) libraries, players can perform actions in the game without relying on visual information." However, they conclude that most reviewed games need significant improvements for the VI community: Games show deficits in entertainment and challenging aspects, or user interface (UI) properties, such as text size. Also, VI players often play non-accessible games with an auditory experience that can guide the player, but they are still not provided with enough audio cues for basic actions [22].

The prototype that will be developed starting in section 3 matches the categorization of navigational games in terms of audio game aspects, defined by [22]. However, it is more than just an audio game as the core gameplay includes graphics to seamlessly bring together players with and without sensory disabilities. This approach follows the notion of [19]; they studied inclusiveness and accessibility in Game Sound Research. They emphasize the importance of creating an equalized gaming experience where players of different abilities can enjoy the same game as their peers. Unlike current audio games that separate VI players from sighted and DHH players by omitting visual cues, the objective is to develop a game that bridges this gap and provides an inclusive experience for all players.

Further key findings reveal that auditory cues play a crucial role as spatial information can be experienced in the hearing modality from auditory cues, thereby impacting player performance, enjoyment (experience), and motivation. Hence, their primary recommendation is to incorporate audio feedback as navigational aids to foster the inclusion for VI players. Lastly, they underscore the importance of actively involving VI and DHH players in the game design process.

2.1.2 Solutions for Deaf and hard-of-hearing individuals

Developers utilize audio cues in video games for various purposes: conveying emotions, warning of danger, or hearing a melody. However, this information is not accessible to people with hearing loss when the game does not provide visual or haptic cues. A study by [18] points out that games are often problematic for DHH players because auditory cues are used for crucial information, negatively impacting player experience - suggesting visible indicators in players' sight. In addition, haptic cues (e.g., vibrations or pressure) can effectively convey directional information and improve performance in highly visual settings [18]. In addition, adjustable subtitles and closed captions with a transparent background are considered effective ways to convey information. Further, [18] tested audio, haptic, and visual cues on participants and found that additional cues in contrast to one effective cue do not further contribute to performance improvement. Still, players like to activate all cues without any impact on their performance, as the entirety of cues could bring further benefits [18].

Two games that have been well received by the deaf community [20, 25] are 'The Last of Us Part II'[6] (2020) and the remake of 2013 'The Last of Us Part I'[7] (2022) with a variety of accessibility settings, such as directional arrows or a visual indicator to solve tasks within a specific range and timeframe. Also, VI players, are enabled to fine-tune audio cues for different objectives [20].

2.2 Research Questions and Hypotheses

Based on the findings of the abovementioned references; and following the methods to be applied to investigate the objectives, a main research question and two sub-questions have been derived. The main research question is: *To which degree do audio orientation and sound representation cues strengthen inclusiveness and improve player performance for visually impaired, deaf, and hard-of-hearing players in 3D action-adventure environments?* The sub-questions are: SQ1*: What characteristics of sound design choices and audio orientation cues are more effective in strengthening inclusiveness?*

[6] https://en.wikipedia.org/wiki/The_Last_of_Us_Part_II
[7] https://en.wikipedia.org/wiki/The_Last_of_Us_Part_I

SQ2*: Do sonic-based inclusiveness components improve the player performance and experience in 3D action-adventure video games?* Based on these questions, three hypotheses are derived: H1: Sound design and sound representation techniques identified in previous research, including statements, wishes and needs from people concerned, result in techniques to strengthen inclusiveness for VI and DHH player in 3D action-adventure environments. H2: There are some sound characteristics which are more efficient than others in strengthening inclusiveness. H3: The addition of inclusiveness components to a video game can improve and equalize the performance and experience of VI or DHH players compared to that of other players.

2.3 Development Foundation

The investigation of the related work (section 2.1) was carried out in a literature review and will incorporate the results into the first prototype explained in the next section. The author used databases and descriptors to narrow the research area in Human-Computer Interaction (HCI). These databases were Google Scholar[8], ACM Digital Library[9] and the KTH Library[10]. Articles were selected based on the descriptors: Video Games, Inclusiveness, Accessibility, Vision Impairment, Deaf and hard of hearing, Sound Design and HCI. Queries with various combinations of the descriptors have been filtered down to display the years 2010 to 2021 to reflect current technological advances. These results were then further narrowed down using publication types and quantitative metrics such as counts of citations and downloads. Fifty articles were selected that met the research questions and were eligible for shortlisting. Of this selection, emphasis was placed on choosing the most recent publications and those close to the topic, whereby ten articles remained. Furthermore, since video games have a strong digital aspect and new developments are often first discussed on social networks, the platforms YouTube, Facebook, and Reddit were also scanned. Based on these results and an abstract idea of a video game, a Game Design Document is created [5, 16] in the next section.

3 DEVELOPMENT

This section reports the game development process, starting with the Game Design Document - listing aspects such as the game mechanics, graphics, and soundscape. The next stage is prototyping - explaining the first prototype, followed by the interview results gathered with VI and DHH people, guiding the way to the second iteration. Then, adjustments are listed based on the pre-study results, resulting in the third iteration. The final step is the conduction of the main study.

From now on, the author uses abbreviations:

- *Non-disabled* (Referring to the regular game mode of the prototype without applied accessibility functions; used by non-disabled participants or participants using glasses to adjust for lesser vision impairments).
- *VI* (Regular game mode plus activated Inclusion Mode; used by vision-impaired participants without any form of visual aids).
- *DHH* (Regular game mode plus activated Inclusion Mode and Audio Visualizer; used by deaf and hard of hearing participants with and without hearing aids).
- *BF* (Blindfolded - Regular game mode with a black screen plus activated Inclusion Mode; used by non-disabled and minor vision impaired participants).

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[8] https://scholar.google.com/
[9] https://dl.acm.org/
[10] https://www.kth.se/en/biblioteket

3.1 Game Design Document

The Game Design Document aims to align the game's vision with the Audio Director of the company Massive Entertainment[11], a Swedish video game developer based in Malmö, and the university supervisor. It serves as a foundation to discuss and iterate the game's vision, the features, and to keep track of the ambition and plan, and reduce miscommunication and time-wasting [16]. The document entailed the concept, target audience, gameplay, game mechanics, technical platform, audio environment, and accessibility features – briefly summarized:

> Tap Tone is a 3D first-person action-adventure game where players explore a forest with sonified impressions to practice their auditory skills by combining melodies. The player will find 3D objects that emit notes in intervals. The player must listen closely and compare the notes. Once the correct notes appear, they hit the 3D object with a projectile, which is released with the click of a button to match it into a given melody sequence. The player must aim at the 3D object and hit it from a distance. The game implements audio cues, such as rustling leaves, whistling birds, or a woodpecker, to guide the player to the following note. In addition, notes gradually increase their intensity when the character gets closer, helping the player to follow the sound to the position of the note.

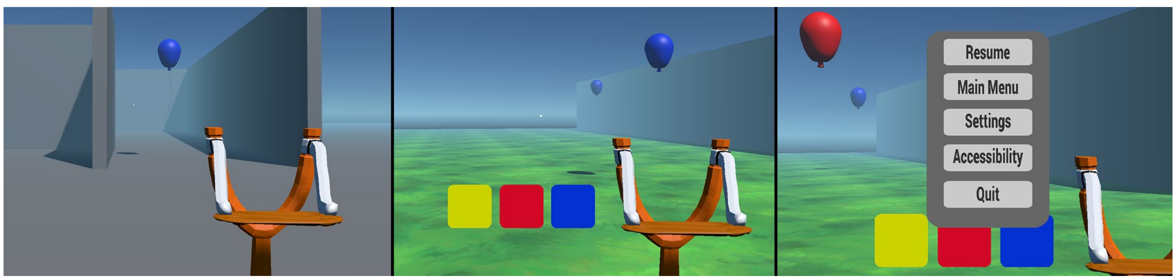


Figure 2: First prototype (left to right): Implementation of target aiming with balloons; adding a color code; adding an elementary menu.

> The game is for anyone starting from age 10. Tap Tone emphasizes inclusiveness components that allow VI or DHH individuals to participate in the game. The duration of the gameplay will take from 10 to 20 minutes. The target platform is Windows, as this is the development platform. Audiokinetic Wwise (Wwise) is chosen as the audio engine middleware. Wwise generates soundbanks which Unity accesses. Dolby Atmos renders spatial sound to headphones or speakers. Hence, the audio endpoint in Wwise is set to Spatial Sound by enabling the System Audio Objects, causing Wwise to pass the audio and positional data from the game into the endpoint renderer (Dolby Atmos). However, at the time of implementation, Dolby Atmos only provides 16 Audio Objects. Therefore, audio Objects are downgraded into the game's main mix when this number is exceeded. The soundscape is held peacefully and highlights audio cues, letting the player pay close attention to musical and auditory details.
> The accessibility guidelines featured in the game, among others: Ensure no essential information is conveyed by sounds alone[12], Provide a visual indication of who is currently speaking[13], use surround sound[14], Provide separate volume controls or mutes for effects[15], Use distinct sound / music design for all objects and events[16].

[11] https://en.wikipedia.org/wiki/Massive_Entertainment
[12] https://gameaccessibilityguidelines.com/ensure-no-essential-information-is-conveyed-by-sounds-alone/
[13] https://gameaccessibilityguidelines.com/provide-a-visual-indication-of-who-is-currently-speaking/
[14] https://gameaccessibilityguidelines.com/use-surround-sound/
[15] https://gameaccessibilityguidelines.com/provide-separate-volume-controls-or-mutes-for-effects-speech-and-background-music/
[16] https://gameaccessibilityguidelines.com/use-distinct-sound-music-design-for-all-objects-and-events/

3.2 First Prototype

The first prototype (Figure 2) is based on the Unity First Person Controller (FPC) from the Starter Assets[17] and the Wwise Unity Integration[18]. As the Game Design Document developed during the first and second prototype, the first version contained a simple parkour and a slingshot to interact with 3D balloons (Figure 3). In addition, ray casting and coordinate calculation were used to introduce a sound-controlled aiming function specifically for VI, which was initially the study focus. However, after interviews, this proved impractical and undesired (Section 3.3).

Basic audio features were added to interact with the game and player, such as States, Switches, and RTPCs. With this, general performance settings could be set, such as obstruction (a low-pass filter reduces high frequencies when an object obstructs the sight between the player and the balloon). Five balloons were generated at random positions (matching a five-note melody). The player was to collect the notes based on the encounter sequence. On encounter, one tone randomly changed the pitch in a 3-second interval between every seven possible diatonic major notes. However, only the correct note counted as a successful hit; a wrong hit caused the balloon to disappear to a random position on the map to prevent continuous firing without listening for the right note.

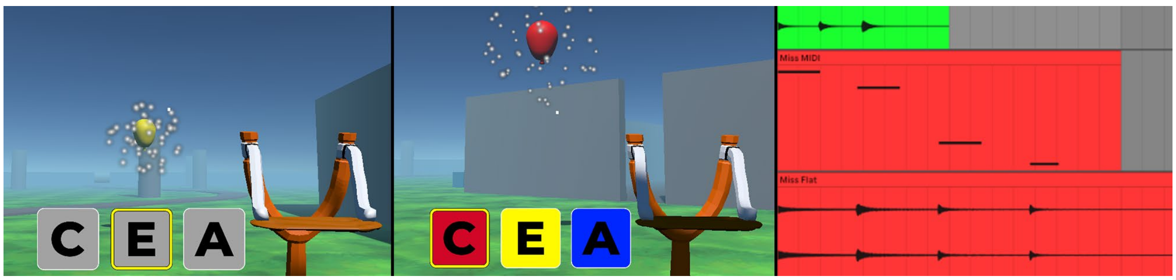


Figure 3: First prototype (left to right): Adding notes in Wwise and a related UI for note letters; Experimenting with a Color Visualizer; Creating sound effects in Ableton Live.

Moreover, guitar-recorded music was implemented with Wwise for the game's background, with decreasing intensity once a player encounters a 3D object. The intensity of the music was mapped based on the distance to the target to a low-pass filter via an RTPC parameter from Wwise. Also, an experiment of a Color Visualizer turned into a first version of the Audio Visualizer for DHH: Notes are color-coded and reflected in the UI.

In retrospect, several short levels were intended for the game at this time, with the idea of introducing a new melody at each level. Hence, great effort was placed into developing the backend, resulting in a lightweight scaling of the game: Designers can enter note letters of a new melody into an interface, and the game automatically generates new levels by itself. However, the final decision for the study setup opted to use only one large level. First, the reasons were that the environmental design of a level consumed significant amounts of time, which took away valuable time from the actual VI focus. Second, the inclusion features and mechanisms can be tested in one level. Third, a single run takes up to 45 minutes for VI, which is the study's goal, including a questionnaire and interview, each of which takes about 10 minutes.

3.3 Interviews about Requirements

While developing the first prototype, the author initiated one-on-one interviews with the target group of sensory disability to let them express first-hand wishes and needs for the games industry. For this purpose, an interview invitation was

[17] https://assetstore.unity.com/packages/essentials/starter-assets-first-person-character-controller-urp-196525

[18] https://www.audiokinetic.com/en/library/edge/?source=Unity&id=index.html

published in a newsletter of the "Blinden- und Sehbehindertenverein Hamburg e.V." [10]. Five VI people responded, with whom online interviews were conducted via Mail, Discord, and WhatsApp. It also established contact with the community "Flügel an Flügel" [24], the developers of the SkuAddon [29], which lets blind players take part in World of Warcraft (WoW) together with sighted players. Contact was also made with the "Nintendo Deaf Championship" [15].

The first interviewee became blind due to a genetic disease. Since then, he gained experience with 3D games by developing a blind-friendly add-on for WoW. The interviewee identified four essential features for a 3D game:

First, a wayfinding (navigation) function; second, an audio menu; third, individual settings for voice, sounds, and music; and lastly, placing the accessibility settings at the start of the game. Likewise, it became apparent that mouse movements for VI are short of enjoyment and too slow in-game. This is because mouse movements in a game context are not tailored for their specific needs and are considerably slower when compared to distinct keyboard commands. Hence, the initial sound-controlled aiming function was canceled from the study focus. Further, the WoW add-on uses soft targeting by automatically aiming at targets based on the character's orientation. However, this function is not pursued in Tap Tone since sound-controlled independence in aiming should still be maintained. Also, he highlighted that accessible sound design must blend naturally into the game.

The second interviewee confirmed the impracticality of using a mouse. He perceives an irresolvable drawback relating to the aiming latency when waiting for the audio feedback compared to players who can visibly see the target. Another thing that has become evident is the need for enlargeable UIs as the person still sees colors and contrasts when they are close to the screen.

With the remaining persons, the author got further insights into their perspectives by learning about well-made audio games and well-implemented sound design examples in present games.

Next, the author interviewed a person suffering from Usher syndrome, characterized by visual impairment and deafness. The person has decided against wearing a hearing aid and cannot perceive frequencies except low ones in the form of vibrations on the skin. The person cites haptic supports, such as controller vibrations, as a potent aid for DHH people in video games. Alike, for DHH with remaining hearing, games should have background music turned down and gameplay sounds turned up (e.g., the footsteps of an opponent). Finally, this person aligns with the related work that the quality of subtitles in video games and their background color and size often need to be improved.

Further discussions with DHH people in the community /r/deaf [32] revealed that sound representation techniques always depend on an individual's needs. Developers should always ensure a game can be played without sound – substituted by subtitles and closed captions.

3.4 Second Prototype

The author based the second prototype (Figure 4) on the previous development and adjustments based on the insights from the interviews. In the first step, the overall game was polished by replacing the parkour with a Unity asset pack containing a graphical 3D forest environment[19]. A start menu, in-game menu, and instruction screens were designed in an Adobe Photoshop project. The total of inclusion features for VI were gathered under the option: Inclusion Mode; in addition, the inclusion features for DHH under: Audio Visualizer. Furthermore, a conductor's baton replaced the slingshot, and the 3D notes replaced the 3D balloons - both modeled in Blender.

[19] https://assetstore.unity.com/packages/3d/environments/landscapes/free-low-poly-nature-forest-205742

3.4.1 Sound Design for Audio Orientation Cues

In a second step, audio orientation cues were added so that players distinguish the localization of a sound source with their ears and, therefore, can follow the sound to a specific location. This effect is accomplished by distributing sounds on the azimuth position and calculating differences in the timing and intensity of sounds to know how they arrive at both ears. Distance information for far away objects can be achieved by the sound sources having lower amplitudes or lower frequencies. Low frequencies are calculated by analyzing the interaural time difference and the interaural level difference for high frequencies. That enables binaural processing: The brain compares movements of both eardrums to synthesize auditory objects [30, 31, 34]. Sounds on the elevation position are used with reflection and refraction to help with disambiguation [23]. These elements are used in the sound engine renderer of Dolby Atmos with object-based audio using HRTFs, which is well suited for "3D emitters, such as birds in an outdoors environment" [23].

Figure 4: Second prototype (left to right): Designing the forest environment; Regular UI; Contrast mode of the UI

Two audio orientation cues were chosen to give the players hints about their destination: First, a clear audio signal was placed on the X and Z coordinate of the 3D note, staged as a small jam between the note and a forest inhabitant. Various versions of this cue play at random intervals of 20 and 40 seconds - with a slow increase in intensity when approaching the object. This cue provides the player with information about the cardinal direction and the airline distance to the 3D note. Second, an audio cue, such as rustling leaves, whistling birds, and a woodpecker, is placed on the closest tree to the 3D note within a radius of 50 units (the dimension of one unit is here defined as one meter) around the player. Nearby trees were determined within the radius and stored in an array. A loop iterates through the array and determines the tree with the shortest distance to the 3D note. The algorithm then places the audio cue on the determined tree. This audio cue does not provide the player with a direct airline. However, it lets them orientate bit by bit in the right direction - achieving more game depth, excitement, and duration by hiding more apparent clues of the airline direction as the cue occurs every 10 - 20 seconds.

In addition, as the forest is a large area with many obstacles, particularly challenging for VI, each obstacle (tree and stone) is assigned a continuous sound. For trees, it is a tree creaking sound effect, attenuated with an intensity of amplitude, minor spread property, and decreasing high frequencies with an increase in distance in a radius of 15 units around a tree. Similar attenuation settings are applied for stones, yet with the issue that a stone itself does not emit sounds. However, minimal white noise was applied on the stones as a preventive sound to avoid a collision. However, due to the equal distribution of amplitude, white noise could also be considered unsuitable for this use case.

Field recordings of birds, crickets, and winds extended the soundscape. Other extensions included varying footsteps based on the terrain material, character grunts when stuck, flowers and bushes snapping off when passing through, and other small sound details.

3.4.2 Sound Design Components for the Vision Impaired

The third step entailed audio inclusiveness components for VI - based on the components of the previous section, plus additions specifically for VI: Voice-overs for the menus, instructions, and in-game commands with replay functions (which relates to the guideline: Allow all narrative and instructions to be replayed[20]). Both menus received sliders to adjust the voice, music, and effects volume (relates to: Provide separate volume controls or mutes for effects[21]). The FPC was adjusted to be accessible solely on a keyboard, including the camera perspective, and an Audio Compass was added, announcing cardinal directions.

Figure 5: Second prototype (left to right): The final forest environment; Contrast mode of instructions; UI including five notes.

Lastly, the author created an Audio-Obstacle-Illumination (AOI) mechanism: The game stores obstacles around the player in a small radius with a single key press. Since the melody contains five notes (Figure 5), an algorithm determines the five closest obstacles around the player, sorted from the shortest to the farthest distance. In that order, the melody plays one note after the other on that specific obstacle as a spatialized audio object. These audio cues should provide the player with a quick all-around scan of the environment, allowing them to gauge the location of the five closest obstacles - and plan their following path (refers to: wayfinding function).

3.4.3 Sound Representation Components for the Deaf and Hard-of-Hearing

In a fourth step, supporting components for DHH were implemented. The term "Representation" regarding arts is defined by [33] as: *"[…] the use of signs that stand in for and take the place of something else. […]. Signs are arranged in order to form semantic constructions and express relations."*. The author uses this representation aspect of semantic construction and relations to transmit the information value of audio cues with a visual representation to DHH. Hence, based on the interviews and accessibility guidelines, the following components were chosen: Color coding of the notes (Audio Visualizer), object-based audio, subtitles, closed captions, a direction indicator, and voice-over instead of AI.

Although overlapping with VI components yet fulfilling other intentions: audio objects enable dialogue enhancements by delivering the dialogue in separate objects. Therefore, people who are hard of hearing can adjust the mix between the dialogue and the background signal to their preferences [7]. In addition, the voice-over is recorded with the author's voice instead of using a text-to-speech AI assistant. That is because [28] pointed to findings of a study*: "Hard of hearing listeners could understand speech in noise better when spoken by a familiar voice, spouse or close friend, than by a stranger"*.

[20] http://gameaccessibilityguidelines.com/allow-all-narrative-and-instructions-to-be-replayed

[21] https://gameaccessibilityguidelines.com/provide-separate-volume-controls-or-mutes-for-effects-speech-and-background-music/

Next, the author added subtitles and closed captions to display contextual voices, background noises, or other relevant information. In addition, to convey the information of the audio orientation cues, that is, the direction estimation when a sound appears as 3D audio, a 3D arrow lights up on the screen for 3 seconds when a sound cue plays.

3.4.4 General Features

In the last step, the author placed the background music solely in the menu to avoid confusion in-game. Furthermore, the intensity of the soundscape was significantly increased for non-disabled - by increased and unbalanced audio volume, use of excessive reverb, lower attenuation of the target notes, and visual difficulty by reducing the size of 3D tones. Therefore, increasing the difficulty for the Non-disabled and creating a balance between Non-disabled, VI, and BF.

Furthermore, the emitted notes for a single tone were reduced from the diatonic major notes to only 3 notes, which means the chance to wait for the correct pitch is one-third, compared to all seven diatonic major notes, which was one-seventh. Finally, a light reverb was placed over the soundscape, and a practice mode was introduced to give participants a chance to learn the controls and thus improve the data collection (referring to: Include a means of practicing without failure, such as a practice level or sandbox mode[22]).

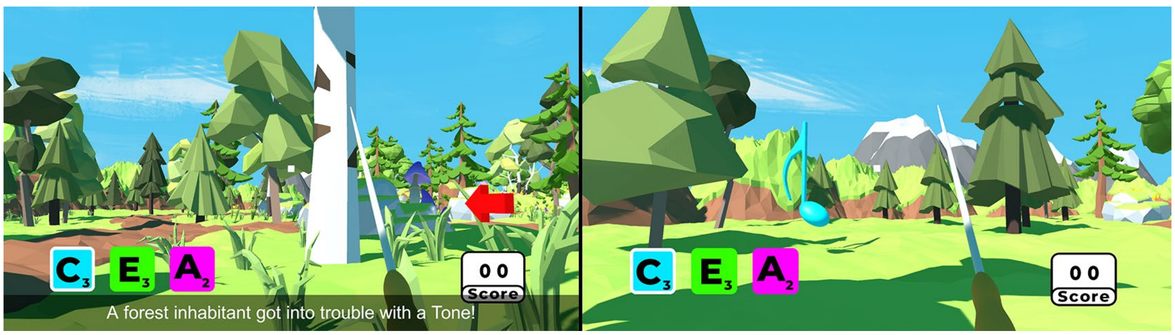


Figure 6: Third prototype in Inclusion Mode with Audio Visualizer: Subtitles and Arrow Direction Indicator (left); The note "C" in the third octave is shown with a light blue color.

3.5 Pre-Study and Third Prototype

The pre-study with the second prototype was intended to test the game, receive feedback, and assure the quality of the questionnaire and evaluation methods. Three participants were invited and asked to install the game on their PC, further, to run it, follow the instructions through the game, send back the data log, and fill in the questionnaire.

The first person is deaf, defined as male, and is 37 years. We communicated by typing in a chat. The play went solid, with a rated game experience of 7 points out of 10. He also confirmed the text size as suitable and labeled the Audio Visualizer as *"very important"*. The time recorded was 9 minutes from the end of the practice mode to finding all tones. The second person is non-disabled and completed the game in 11 minutes. We were connected through voice chat. Instructions were skipped and not read as they were too long for the person's liking and expected to be repeated in-game.

The third person is vision impaired, defined as male and blind for 31 years. We were connected through voice chat. The overall study procedure took over 60 minutes, including an in-depth explanation from the author. That exceeded the goal of 45 minutes per participant and failed in allowing the player to finish the game without the author's intervention.

[22] http://gameaccessibilityguidelines.com/include-a-means-of-practicing-without-failure-such-as-a-practice-level-or-sandbox-mode

Furthermore, issues arose with the AOI as it needed to be clearer to figure out what the notes do (causing the participant to run into several obstacles). Also, the sample length of the audio orientation cues needed more extended playtime to provide improved orientation (they played every 20 seconds with a length ranging between 1.5 to 5 seconds). In addition, the participant uttered preferred sounds, which should be continuous or occur more often. Lastly, it was difficult to aim at the objects; the bird-squeaking indicator needs to be more informative when the aim is aligned with the target.

As a result, the author reworked the instructions, explained further instructions in-game, reduced the melody from 5 to 3 notes, located the notes closer together, and increased the occurrence of audio cues. Moreover, the author reduced the obstacles within the environment and spread them further apart. To improve the AOI, the author replaced the notes with sounds matching the objects: Trees emit sounds like falling, being chopped, or sawed off. Stones sound as if a pickaxe hit them, or a rockslide is unleashed. Lastly, an audio indicator for the aiming function has been added: A continuous sine wave is triggered when the player is within 25 units of the target. The closer the crosshairs are dragged to the target, the higher the pitch rises until, finally, the bird-squeaking appears. The total impressions resulted in creating Table 1.

Table 1: Final list of implemented components (N = Non-disabled).

ID	Condition	Component	Description
C1	N, VI, DHH	Audio Cues	Guidance to the next tone (birds, rustling leaves, woodpeckers).
C2	N, VI, DHH	Audio Settings	Configuration based on personal preference.
C3	N, VI, DHH	Character Controls	Balanced based on condition.
C4	N, VI, DHH	Soundscape	Balanced based on condition.
C5	VI, DHH	UI Contrast Mode	UI with white background and black font.
C6	VI	Audio-Obstacle-Illumination	Avoiding obstacles by the perception of distance through sonification.
C7	VI	Audio Compass	Announcement of cardinal directions (North, East, South, West).
C8	VI, DHH	Voice-Over Audio Menu	Read aloud of self-recorded menu items and instructions.
C9	VI	Audio-Aim-Guidance	Rise and fall of pitch and “on-target” notification (bird squeaking).
C10	DHH	Arrow Direction Indicator	3D arrow directing to the next target in line of sight.
C11	DHH	Subtitles/Closed Captions (CC)	Audio cues and in-game instructions are subtitled.
C12	DHH	Audio Visualizer	Color coding of the note and pitch of tones.

3.6 Main Study

The main study procedure followed a similar structure of (online) playtesting as [12]. The author decided to conduct the study online because many participants with sensory disabilities had signed up to participate from various countries – yet on-site participation was also utilized. VI and DHH represented two groups – and non-disabled were divided into two groups: Non-disabled and BF (Refer to Section 3 for further details on these groups).

This served three reasons: First, the installation, playthrough and fill-in of the questionnaire is time-consuming for VI. Hence, the burden for one participant would become too great in a test setup with two runs, hence participant could stick to a single run. Second, it is necessary to test components with specific groups: For instance, one group requires sight to test a visual arrow. Another group requires an auditory sense to experiment with the quality of the soundscape. Therefore, the study design exposed each participant only to one UI, turning the study into a between-groups design. Third, gathering data from non-disabled people playing the Inclusion Mode blindfolded appeared attractive to compare the data points with the data from VI players.

Participants were instructed to play on a given Windows PC; or install the application on their PC. In addition, the protocol asked to remove any visual aids (for VI), to play with a headset and set up their game mode. Participants followed mainly the game's instructions, yet they could ask general questions. In the end, the application printed a log file, which was shared, containing time measures, the number of key clicks, and coordinate points. Lastly, participants had to fill out a questionnaire[23] and were asked to add verbal or written feedback to encourage discussion and feedback.

3.7 Participants

The participants were invited through the established interview channels and social media platforms. One of the difficulties encountered involved the low response rate on a single social platform, where each invitation typically resulted in zero to two positive engagements. As a result, a significant amount of time was required to accustom oneself to each platform or community and understand the appropriate code of conduct before finalizing the invitation. Furthermore, seeking official permission was often necessary to obtain approval for a public research invitation, as community members are expected to contribute content that is relevant, factual, and beneficial. Nevertheless, 25 people committed in total. Whereby 8 people were classified as VI (Table 3), 6 as DHH (Table 4), 5 as Non-disabled (Table 2), and 6 as BF (Table 2).

Table 2: Participants divided into Non-disabled (N) and Blindfold (BF) condition

Participant	Age	Gender	Condition	Participant	Age	Gender	Condition
P1-N	24	Male	Non-disabled	P6-BF	25	Male	Blindfold
P2-N	29	Male	Non-disabled	P7-BF	29	Male	Blindfold
P3-N	23	Non-Binary	Non-disabled	P8-BF	19	Male	Blindfold
P4-N	54	Male	Non-disabled	P9-BF	33	Male	Blindfold
P5-N	34	Male	Non-disabled	P10-BF	24	Male	Blindfold
				P11-BF	29	Male	Blindfold

Table 3: Participants classified as Vision Impaired (VI)

Participant	Age	Gender	Impairment	See handwriting
P12-VI	26	Male	Difficulty reading things from afar.	Yes
P13-VI	37	Male	Completely blind (since birth).	No
P14-VI	31	Male	Partially sees out of the left half of the right eye.	Yes
P15-VI	52	Female	Approx. 50 % vision left.	Yes
P16-VI	17	Male	Completely blind (since birth).	No
P17-VI	31	Male	One eye 100%, One eye 0 %.	Yes
P18-VI	27	Female	Approx. 30 % vision left.	No
P19-VI	24	Non-Binary	Colorblind - Approx. 60 % vision left.	Yes

Table 4: Participants classified as Deaf and Hard of hearing (DHH)

Participant	Age	Gender	Impairment	Type	Hearing aids
P20-DHH	33	Male	Deaf (Profound)	Bilateral	Cochlear implant
P21-DHH	43	Male	Deaf (Profound)	Bilateral	No hearing aids
P22-DHH	36	Male	Hard of hearing (Profound)	Bilateral	Cochlear implant and Behind-the-ear
P23-DHH	31	Male	Hard of hearing (Profound)	Bilateral	Cochlear implant
P24-DHH	23	Female	Hard of hearing (Severe)	Bilateral	Behind-the-ear
P25-DHH	23	Female	Hard of hearing (Profound)	Bilateral	Cochlear implant and Behind-the-ear

[23] https://forms.gle/wefeJzX9sT4VT7257

4 RESULTS

The results section will start with the report of the players experiences (4.1), followed by players performances (4.2) – both for Non-disabled, VI and DHH. This is followed by the report of VI components (4.3) and a comparison of the paths between Non-disabled, VI and BF (4.3.1). Finally, the components for DHH (4.4) and for all groups in common (4.5) is reported.

4.1 Analysis 1: Experience

In this section, the author analyses the participants through logged in-game data for total playtimes in between the groups Non-disabled, VI and DHH. The rated experiences for VI and DHH were expected to not deviate significantly from Non-disabled. A One-way ANOVA was performed to measure the means of the conditions. The author had the following hypotheses: *H0: No significant difference in means between groups; Ha: Means between groups differ*. It is found that the difference in average experiences for DHH (Mean = 5.33; SD = 2.25), Non-disabled (Mean = 7.8; SD = 1.48), and VI (Mean = 8.25; SD = 2.05) is significant (f (2) = 3.963; $p < 0.04$). Consequently, the null hypothesis (H0) is rejected - there is a significant difference in means (Figure 7). A Tukey post-hoc test confirmed the ANOVA results with the greatest difference in means between VI and DHH (diff = 2.91; $p < 0.039$), showing a significant difference. This result suggests that the experiences, especially between VI and DHH, differ within the usage of implemented inclusiveness components. However, the VI and Non-disabled difference is slight (diff = 0.45; $p < 0.917$). Therefore, the author conducted a Welch's two-sample t-test between both groups with the following hypotheses: *H0: Both groups have equal means; Ha: Both groups have non-equal means*. The t-test revealed that the difference in rated experience between VI (Mean = 8.25; SD = 2.05) and Non-disabled (Mean = 7.8; SD = 1.48) is not significant (t (14) = 0.457; $p < 0.656$). The p-value is above 0.05. Hence the author does not reject H0 and concludes that both groups have statistically equal means - suggesting that the experiences between Non-disabled and VI are approximately similar.

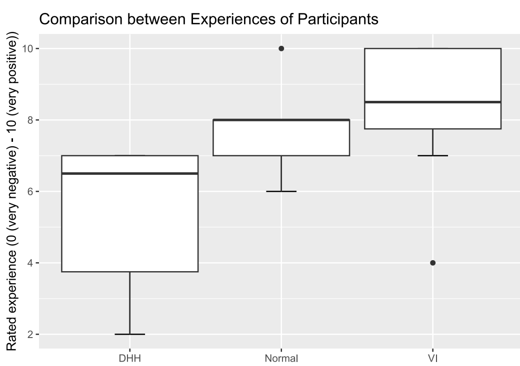


Figure 7: Boxplot comparing the rated experiences (0 – 10) for DHH, Non-disabled, and VI (Section 4.1).

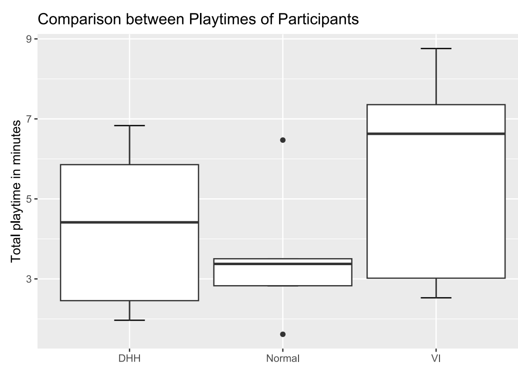


Figure 8: Boxplot comparing the total times in minutes for DHH, Non-disabled, and VI (Section 4.2).

4.1.1 Experience Indicator

A summary of means is displayed in Table 5 - showing VI participants encountered the most substantial *challenge* (Mean = 2.5) and *effort* (Mean = 2.33) on a scale from 0 (Not at all) to 4 (Extremely). P17-VI and P18-VI, both rated 4 points, which means their challenge and effort were extreme. For instance, P18-VI explained: "*The game should tell that it's okay to hit the tapping several times to distinguish the sounds.*", P12-VI added: "*Hard to catch the idea that quickly*.". However, P13-VI wrote: "*First-sight movement is used, which is more complicated than top down, the game is simple to play, and I had no difficulty finding the different melodies.*".

Regarding soundscape perception, 8 out of 19 participants strongly agree, and 7 agree that it delivers a natural environment. Nevertheless, P19-VI explained about the stimuli reduced soundscape: "*The soundscape felt at times a bit overwhelming to a point where I disregarded a lot of it as 'background noise' and just listened for the note.*". Also, P2-N wrote about the sensory overload: "*The forest sounds were very loud; I stopped looking for the notes with my eyes and relied only on my ears.".*

In summary, the evaluation indicates enjoyment for the game but trouble understanding the instructions. Some understood the principle only while playing, whereby the practice mode was emphasized as helpful. Most problems arose in correctly distinguishing the notes from each other. In addition, some would have preferred a more extended playtime and requested extended activity within the forest to enjoy the natural elements. Another problem was that people with low vision confused the colors of the UI with the colors of the 3D notes, but the UI used colors to indicate the progress in the game. Moreover, DHH players had several difficulties, see section 4.4.

Table 5: Experience indicator based on in-game data (means, total count = 19)

Mode	Challenge (0 – 4)	Effort (0 – 4)	Natural Soundscape (1 – 5)	Sensory Strain (1 – 5)	Perceived Nuances (1 – 5)
Non-disabled	1.5	1.2	4.4	3	4.2
VI	2.5	2.33	4.38	2	4.13
DHH	1.83	2.17	3.17	3.3	3.4

4.2 Analysis 2: Performance

In this section, the author analyses the participants through logged in-game data for total playtime. The playtimes for VI and DHH were expected to not deviate significantly from Non-disabled. A One-way ANOVA was performed to measure the means of the groups. The author had the following hypotheses: *H0: No significant difference in means between the groups; Ha: Means between groups differ*.

It is found that the difference in average playtimes for DHH (Mean = 4.30; SD = 2.07), Non-disabled (Mean = 3.56; SD = 1.79), and VI (Mean = 5.67; SD = 2.45) is not significant ($f(2) = 1.57$; $p < 0.238$). Consequently, the null hypothesis (H0) is not rejected - suggesting no difference in means between groups (Figure 8). A Tukey post-hoc test confirmed the ANOVA results with the greatest difference in means between Non-disabled and VI (diff = 2.11; $p < 0.2378$), showing no significant difference. This result suggests that the playtimes in each group are approximately the same despite sensory disability.

4.2.1 Performance Indicator

From the overview (Table 6), Non-disabled scored the most points (27 points out of 30). It is also noticeable that DHH players triggered the note the least (only 10 times, in contrast to 29 times in Non-disabled and 30 times in VI). Regarding false hits, VI stands out with an average of 2.4; DHH averages 2, with Non-disabled having only 1.2 false notes. Finally, the AOI was not used at all by Non-disabled players. Nevertheless, an average usage of 2.8 times indicates intense usage for VI. DHH also used the AOI with an average of 1.5 times.

Table 6: Performance indicator based on in-game data (means, total count = 19)

Mode	Total Time (Minutes)	Points (Max. 30)	Tap count (Note trigger)	False notes	AOI count
Non-disabled	3.56	27	29	1.2	0
VI	5.67	25	30	2.4	2.8
DHH	4.3	25	10	2	1.5

4.3 Analysis 3: VI Components

This section examines the VI components from Table 1, more specifically the Audio Menu, AOI, Audio Compass, and Audio-Aim-Guidance, and comparing the participants paths of Non-disabled to VI and BF.
Regarding the Voice-Over Audio Menu (C8), 4 out of 8 participants strongly agree, and 3 agree that it is helpful to them. The same consensus is true for finding specific menu items they are looking for. However, P19-VI disagrees and states: *"It would be helpful if the introduction actually included some of the sounds instead of just describing them.*". A similar picture emerges for BF: 4 out of 6 participants strongly agree, 1 agrees, and 1 is neutral. Moreover, P11-BF adds: "*The menu is very good.*". On average, VI scores 4.3 points out of 5, and BF scores 4.4 points for the Audio Menu.

The next component is the AOI (C6). The results for VI (Figure 9) reveal that most participants rate the efficacy with 3 points out of 5, or higher (which translates to avoiding obstacles). One person disagrees with the efficacy – but does not leave a reason. However, P13-VI explained: "*I didn't have much perception of the ditches or other obstacles until the voice told me that there was an obstacle and therefore, I had to choose another route.*". The evaluation for BF is similar (Figure 10) yet lower overall. 3 BF participants disagreed; P6-BF explained: "*The noise of the saw is too loud, and the sounds of the stones were irritating*.".

Moreover, P11-BF said: "*I was overwhelmed because I didn't understand AOI. For example, the sound of a tree falling irritated me, I didn't know if I had to pay attention because a tree was falling in my path. This pulled me out of the immersion but otherwise I got along fine*.". In contrast, P7-BF understood AOI well but criticized the volume and length of the function. Moreover, he did not know exactly the distance to the obstacles but could roughly estimate it.

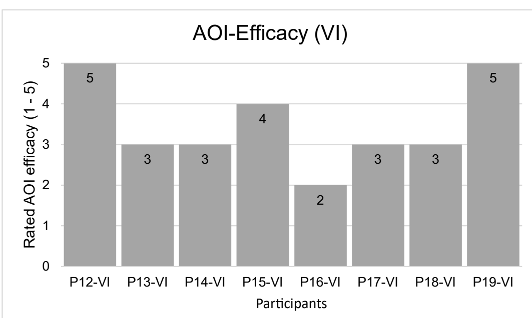


Figure 9: Rated AOI-Efficacy for the VI.

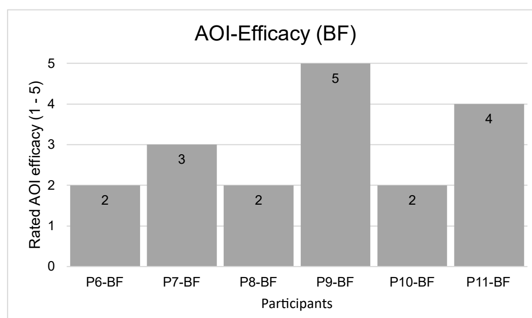


Figure 10: Rated AOI-Efficacy for the BF.

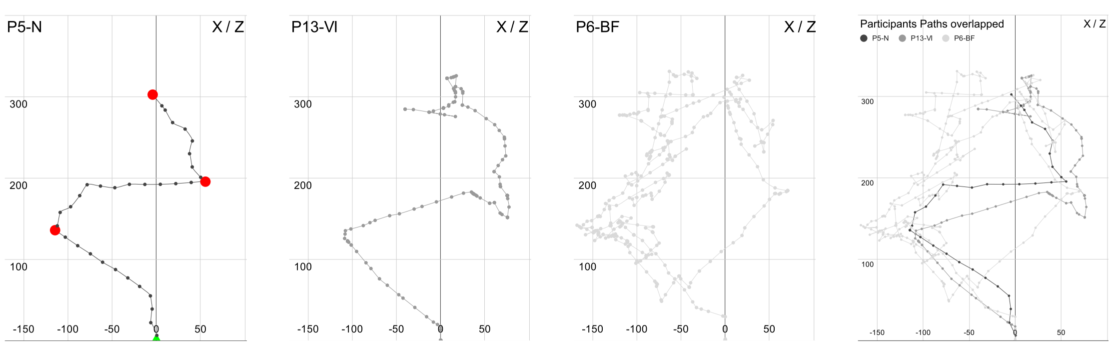
The usefulness of the Audio Compass (C7), which is the announcement of the cardinal directions, is, on average, rated with 3.5 points out of 5 for VI, and for BF with 3.67 points out of 5. Half of the BF participants agreed that they could only navigate using the Audio Compass. However, for VI, only 2 participants agreed, and 6 participants could have played without it. For example, P14-VI explained: "*In some games with good enough sound design for the soundscape and environment, a read out loud compass may not be entirely needed due but is always good to have.*". Furthermore, P19-VI added: "*The compass was annoying; I could not concentrate on the sounds.*", also P11-VI noticed that the triggers overlap when the AOI is activated while moving with the Audio Compass.

The Audio-Aim-Guidance (C9) function was essential, especially for BF participants - 5 out of 6 strongly agree with the function's effectiveness and helpfulness, with an average of 4.67 points out of 5. For VI, points accumulate only 3.5 points on average. BI participants also appreciate the bird chirping with an average of 4.5 points out of 5, whereas it only accumulates 3.25 points for VI. P18-VI said: "*The rising and falling pitch was too loud and the radius too large, making it hard to hear the notes.*". P7-BF added that the birds chirping was incomprehensible, and several people pointed out that it is challenging to combine all the audio cues to match the note, with the bird chirping also being quite loud.

4.3.1 Path Comparison of Non-disabled against VI and BF

Through logging the X- and Z-axis of the player's coordinates, retrospective character paths around the forest environment were drawn into individual charts. In the following, Non-disabled is compared with VI and BF. Figure 11 (a) shows the path of P5-N and represents the optimal path. The participant starts at the origin (green triangle) and moves to the first red circle, which is the first tone of three. However, the notes' spawn point randomly differs from one participant to another by a few units. Each interval between two grey shaded dots indicates a five-second interval. The participant moves on to the next red circle until the last note is collected at point: X = -4; Z = 302. It also can be pointed out that P5-N primarily stayed on the environment path made of dirt and that the path by P13-VI (Figure 11 (b)) shows similarity to P5-N.

One notable contrast was the distinct divergence in navigation paths between the most severely sensory disabled in contrast to the blindfolded participants, who performed the worst. Blind individuals display a remarkable ability to follow auditory cues, consistently navigating a defined path. In contrast, blindfolded participants encountered significant difficulties finding the correct path, emphasizing their challenges in relying solely on auditory cues (Figure 11 (c)). These findings highlight the significance of audio-based techniques for blind individuals. Figure 11 (d) shows the overlays of the three paths presented. P6-BF has no close relation to the others.



(a) Path of P5-N; Regular path, red circles indicate one of the three tones

(b) Path of P13-VI; straight forward path, despite blindness (for 37 years).

(c) Path of P6-BF; rumbling around without a clear objective.

(d) The paths of the three participants laid on top of each other.

Figure 11: Comparison of paths traveled by three participants.

4.4 Analysis 4: DHH Components

DHH participants rated the players' experience the lowest (5.33 points out of 10) compared to each other group. For instance, P20-DHH explained: "*I was overwhelmed with the game. The directional arrow got me to the destination, but I* *had to move so that it is exactly straight out. At some point I saw the music object. But I could not judge if it is the right one*.”. This participant played the game twice, once deaf and a second time with a cochlear implant – perceiving the audio cues clearly. More DHH participants have found that voice-over statements were not turned into subtitles. The reduction of subtitles was an attempt to balance between the Non-disabled, VI and DHH, but it showed a perceived neglect of accessibility for DHH. P20-DHH suggests an optimized implementation: “*It would be cool to have an on-screen noise bar. The game "XIII" has steps or sounds displayed on the screen. If sounds come from a place, then it would be better displayed by flickering and not by an arrow (far away = light, near = strong).*”. Moreover, P22-DHH comments on the soundscape: "*The sounds of the birds chirping, and the leaves rattling are quite well done. Perhaps the forest is too dense, and I hear more from several sound sources.*".

Regarding the Arrow Direction Indicator (C10), 2 out of 6 BF participants agree about the effectiveness, 3 are neutral, and 1 participant disagrees; overall, it is rated with 3.17 points out of 5. P22-DHH wrote: "*It has been very clear to me, where a note plays in the forest [...] and I was made aware of it by the arrow, it has already helped me a lot. Especially when you only hear on one side, I tried turning around 360 degrees to localize better. I also noticed that a speaker tells me where north, south, west, or east is.*".

The Subtitles and Closed Captions (C11) received an average rating of 3.17 points out of 5, with 2 people disagreeing about its effectiveness. Most participants pointed out that they wanted the entire voice-overs to be set to subtitles without exception. Therefore, some did not even recognize the subtitles as such. For example, P20-DHH pointed to the game Half-Life 2, where every sound and noise is visually represented, such as footsteps and gunshots. Moreover, P23-DHH added: "*The teller explains a lot, but not everything was subtitled. I still could understand him, but only if I listen careful without spending too much attention into the vision.*".

The Audio Visualizer (C12) has helped but did not contribute to the game's enjoyment. P22-DHH wrote, "*I liked the visualization of the different tones in colors and the displayed octaves also in color. That's good, but unfortunately if you were deaf, you wouldn't know which octave which tones normally belong together. Therefore, I only paid attention by color and was able to determine that way.*".

4.5 Analysis 5: Inclusion Components for VI and DHH

Finally, components for both VI and DHH are presented (Table 7). The Inclusion Mode at the beginning of the game is well received by both groups (VI = 4.75, DHH = 4.5; out of 5 points). Whereby P3-N added: "*Cool would be a preview to see directly which option really changes the game.*". Many VI players positively received the Contrast mode (C5) with an average score of 4.5 points out of 5. P14-VI commented: "*For visual players, a nice dark mode for the menus would be a great addition as they are far less blinding in some cases.*".

Table 7: Inclusiveness components for VI and DHH

Mode	Inclusion Mode (1 - 5)	Contrast value (1 - 5)	Audio Settings (1 – 5)	Human Voice (1 – 5)
VI	4.75	4.5	4.5	2.88
DHH	4.5	3.25	4.5	3.33

DHH participants only rated the contrast mode with 3.25 points out of 5, to which P22-DHH said: "*A big plus I found was the possibility to adjust the contrast for visually impaired people. For most it may still be too bright, in fact it is better if the text is white and on a black background. This way, the eyes are no longer severely blinded by the brightness and allow for easy reading.*”.

The Audio Settings (C2) were rated with 4.5 points out of 5 by both groups, with it being more important for the DHH participants to hear a human voice than an AI voice (DHH = 3.33, VI = 2.88).

5 DISCUSSION

The key findings of the user research are: First, the player experience deviates significantly in 3D action-adventure environments between Non-disabled, VI, and DHH players by implementing inclusiveness components aligning with Table 1. However, it is found that the player experience for VI could be approximately similar to Non-disabled when implementing inclusiveness components incorporating the sound design and sound representation techniques relating to Table 1. Second, it is found that the performance between Non-disabled, VI, and DHH could approximately be similar when relating to the sonic-based inclusiveness components from Table 1. Thirdly, the characteristics of the implemented sound design choices and audio orientation cues that either strengthened or weakened the inclusiveness of VI and DHH were reported, and will be discussed according to effectiveness, experience, and performance in the next section.

5.1 Discussion 1: Experience

Regarding the player's experience, it was hypothesized for SQ2 that the addition of sonic-based inclusiveness components could improve and equalize the experience of VI and DHH compared to that of Non-disabled. In other words, it was expected that each player, regardless of their disability, could participate in the game and ultimately experience the same enjoyment. However, this was not confirmed. The evaluation of the user study has shown that the player experience for DHH participants performs significantly poorer compared to Non-disabled or VI participants.

5.1.1 The Experience for DHH Participants

This result can be accounted for by several factors: First, since the focus was primarily on sound design, the optimization of components for DHH could not be fully achieved. For example, ensuring that the Arrow Direction Indicator functions correctly in all scenarios, further subtitles for displayed text were not fully addressed.

Another contributing factor is that specific audio cues were not adapted to CC format. This decision was made to prevent the game from becoming too easy for DHH players. Typically, audio cues are more challenging to follow, hence they occur in short intervals. Conversely, visual cues were distributed in longer intervals to compensate. However, this approach had a negative impact on the experience of DHH participants, as some could still perceive sounds and noises. That is consistent with the research by [18], showing that auditory cues used for information can negatively impact the player experience for DHH players.

Integrating haptic features, such as controller usage and vibrations, may have potentially enhanced the player experience for DHH individuals. However, Tap Tone omits haptic exploration due to a focus on sound design. Research has also indicated that a single effective cue could be sufficient [18]. Therefore, the findings do not rule against the use of CC or the Arrow Direction Indicator altogether. Instead, they suggest that implementing these components within Tap Tone could have been more effective or that their inclusion may not compensate fully for the enjoyment derived from audio cues. Furthermore, the game's theme appears unsuitable for DHH individuals, especially in a game that heavily relies on music and sounds. Modifications would be required to provide diverse forms of entertainment and educational value without relying on the usage of audio cues. Therefore, universal design in the sense of *Design for All* cannot be applied here since the game design does not target all people with their abilities equally.

Also, providing alternatives or options to fine-tune components is essential: Even though 'The Last of Us Part I' was praised for its Arrow Direction Indicator and used in Tap Tone (C10), one of the DHH participants preferred instead a screen flickering with different strengths based on the distance to the objects.

5.1.2 The Experience for VI Participants

However, it was found that the inclusiveness components for VI players equalized the experience compared to Non-disabled. Three reasons influenced this result: First, the focus on sound design allowed to address a significant amount of available time to blind players and players with a visual disability, while graphical components were treated as secondary. Hence, extensive efforts were placed on intensive interviews and observations, and recording their preferences and requirements. This proximity to the impaired individuals influenced the enhancement, and improvement of the inclusiveness components, which allowed for a progressive expansion of the player experience. This shows the value of conducting interviews and collaboration with impaired players as a promising approach for sound design in video games. Ubisoft's workshop with a blind individual to optimize inclusion components aligns with this approach [8]. Consequently, game developers should consider, for example, to conduct targeted user research, to introduce a dedicated R&D department within the company, and to conduct game tests with target groups.

Second, an accented sensory overload of the soundscape for Non-disabled participants caused a controlled reduction of their experience rating. Otherwise, their experience could have scored higher than that of VI players, which in turn would quickly result in an experience imbalance between Non-disabled and VI. In addition, the theme of the game is specially designed to integrate players with visual disabilities – resulting in non-disabled participants relying on their auditory sense instead of their sense of sight. Therefore, the findings cannot be automatically transferred to other game genres without careful consideration of the game mechanics and the playing environment.

Thirdly, even without sensory overload, the experience of VI could still be similar to Non-disabled through further improvements: The results indicate that the primary challenge faced by VI players is the lack of understanding the game mechanism. Improving the voice-over instructions and adding further audio cues in-game could solve the issue; however, developers need to maintain a level of challenge, as audio games often lack challenging aspects [22]. Also, the soundscape could further be improved by providing fine-tuning options for the Audio Settings, as one VI player was overwhelmed. In addition, Tap Tone has potential to increase the immersive experience within the forest, for instance with a greater variety of soundscape depth and adding weather or day and night cycles for more contrast.

Minor improvements could entail refining the character controls, enhancing the UI, and further research on inclusiveness components. There is still great potential for research and improvements: the author is still in communication with the "Flügel an Flügel" team as they actively work on updates and integrations for the accessibility add-on. These efforts align with the fact that with modifying the characteristics of sound design aspects, VI players can perform actions in the game without relying on visual information [8, 22].

5.1.3 Conclusion of the Experience

The results revealed potential for inclusive sound design but underscored the need for customization to suit specific user needs. For instance, Tap Tone successfully bridged the gap between Non-disabled and VI players, but fell short in the experience for DHH players. Nevertheless, overall improvement could be achieved, since all players could participate in the same game, regardless of using graphics or sounds. However, it is crucial for developers to account for sensory disability in the game design process. It is not sufficient to provide a single-only Inclusion Mode due to the wide spectrum of visual disabilities. For example, low-vision players can enhance their experience by wearing glasses, while blind people solely rely on audio cues. Similarly, accounting for color blindness ensures a smooth gaming experience for all users. While it may be challenging to meet every user's specific request, striving for inclusivity is worthwhile and crucial for strengthening diversity and equality in the gaming industry.

5.2 Discussion 2: Performance

The hypothesis for SQ2 was tested by examining the performance aspects for each player. It was expected that all players have similar playtimes, and comparable numbers of functions and used mechanisms. This expectation was confirmed regarding the playtimes; and further showing similar player performance of VI and DHH players to Non-disabled players.

5.2.1 Performance for Non-disabled, VI and DHH

The significance of the result is influenced by several factors: First, while the means of the playtimes show statistical significance, the spectrum of individual data for VI and DHH is vast. By taking a closer look at Figure 8, the playtimes for VI range from 2.53 minutes to 8.76 minutes; whereby Non-disabled ranges from 1.62 to 3.50 minutes, with only one outlier. The low average for Non-disabled (3.56 minutes) shows that VI (5.67 minutes) still required the longest average time. This is a perceivable difference in playtime. However, substantially shorter compared to the pre-study, with the blind individual taking over 45 minutes - showing the consistency to [11] that auditory information, such as music and sound, influences player performance and experience.

Second, the measurement of playtimes might be an inappropriate measurement of performance for Tap Tone. Due to the genre of a 3D action-adventure game, there is no incentive to reach the goal in the fastest possible manner. Some players apply different play styles and might want to explore the area by taking their time, while others rush to the end.

Thirdly, for the performance indicator (Table 6): The high rate of false notes for VI stands out, which might have been caused by the Audio-Aim-Guidance component, due to distress and disorientation of the rise and fall of pitch, and the bird squeaking. Moreover, one participant stated concentration issues, making it difficult to match the correct notes. Regarding DHH, having a high rate of false notes might be due to overwhelming feelings and a struggle to understand the games' instructions. As a result, some DHH participants could not match the colors on the UI to the note, which aligns with the statement by [9] and shows that Tap Tone has the potential to improve visual cues.

5.2.2 Conclusion of the Performance

The results show that the implementation of inclusiveness components has the potential to strengthen the performance of VI and DHH compared to Non-disabled players. However, the results need to be carefully considered in terms of game genres and individual players, game length, and overall objective of the game.

5.3 Discussion 3: Inclusiveness Components

It was hypothesized in SQ1 that there are characteristics in sound design and audio orientation cues that are more effective in strengthening inclusiveness than others. Research on a Voice-Over Audio Menu found that DHH players are more interested in hearing a human voice than VI players. Despite this, VI players have responded positively to using the menu for navigating the UI. It is important to consider making the menu accessible with screen readers, which the VI community requested. Providing examples of sounds and audio cues in the introductions is important. The value of accessing inclusion settings at the start of a game has been confirmed. However, it is also essential to provide a preview that briefly describes how individual options will alter the flow of the game. Offering fine-tuned options in the Audio Settings can greatly benefit players. For VI and DHH players, a contrast mode that features a black background and white text is particularly helpful.

5.3.1 Components for DHH

While an Arrow Direction Indicator could improve the wayfinding mechanisms for DHH players, screen flickering has shown potential as an alternative. Additionally, subtitles that display each voice-over interaction on the screen, along with closed captions incorporating sound cues, are essential for accessibility. For example, game instructions were presented as a large display image while being read aloud in parallel. However, DHH players prioritized the voice over the visual display. Therefore, using clear subtitles could enhance concentration and comprehension. Finally, an Audio Visualizer could support the game flow, although not necessarily enhance the enjoyment, particularly when the game theme is based on a musical background.

5.3.2 Components for VI

The Audio-Aim-Guidance is found to be essential. It could be strong with a small radius, and omitted bird chirping, as some VI players found it confusing. Also, the rise and fall of pitch need explanation. Additionally, players should be able to temporarily disable the function to allow them to focus on the task. Next, an Audio Compass serves as navigational element, but must be integrated seamlessly to avoid overlapping with other sounds. Further, the AOI is a promising approach when the length of each sound is adjusted and the sounds correlates to the obstacle to avoid confusion, and the sounds should be explained in advance. The usage of the audio cues can also be seen in the path of P13-VI (Figure 11 (b)): even though he is birth-blind (age 37); the path indicates a clear orientation according to the audio cues.

However, BF participants rated the AOI lower than VI players. Firstly, BF players have been placed in an unfamiliar situation, as seen from their path deviation compared to experienced blind individuals (Section 4.3.1). Therefore, sound cues were their only means of wayfinding, highlighting the importance of a well-designed sound system. Any sound cue that caused confusion was negatively perceived by the BF players. Thus, the AOI was not seen as something that enabled them, but rather as a system with missing conditions and confusion.

Secondly, the implementation of the virtual blindfold falls short to accurately replicate the experience of using a physical blindfold. The issue with the virtual blindfold was that participants kept their focus on the screen, which hindered the transfer of the character's position effectively in the same respect as a VI individual. Consequently, the participant's point of reference remained straight ahead, making it difficult to convey the character's location. In contrast, a physical blindfold would completely block participants' vision, relying solely on sound as the only indicator of position. This could be an explanation of the strong deviation from the path of P6-BF in contrast to P13-VI.

However, the BF trial provided valuable feedback on individual notes, note length, and context of the sound, which can be used to improve the AOI. The author believes that there is potential for the AOI to receive a higher score with improvements. Overall, the auditory cues of the AOI converted spatial information into audio, which aligns with [19].

5.4 Implications to Human-Computer Interaction

Finally, for the main research question it was hypothesized that sound design and sound representation techniques identified in previous research and requirement analyses result in techniques to strengthen inclusiveness. It was found that solely reading about the state of accessibility in audio and sound design is not enough. It is essential to receive the requirements directly from impaired people to achieve strong inclusion. Through an iterative process of prototyping, the Tap Tone prototype was able to continually improve and strengthen the inclusion for VI and DHH players. As a result, Tap Tone shows promising results in connecting people with and without sensory disabilities.

5.4.1 Limitations

The relatively small sample size of 25 participants limits the implications of the results to larger populations. Especially, the division of participants into four groups reduced the number of participants per cluster. Furthermore, there were many ways to test various components and only a small selection was selected and implemented. Thereby a high probability exists that neglected components could yield higher inclusiveness.

Additionally, testing the application remotely introduced several challenges. For example, it raised concerns about whether participants followed the instructions to use headphones or wore them correctly (i.e., not swapping left and right). Moreover, it was unclear if participants could hear all audio cues due to differences in their sound systems and if the application's sound quality was consistent across different devices. Additionally, it was difficult to assess if the game was working as intended and if participants were fully focused on the given task, as there was no direct feedback given.

Furthermore, it was not possible to examine to which degree the sound design enhances the performance of sighted players, as the focus shifted mainly to the sound design of VI and DHH players. Additionally, it is challenging to extrapolate these findings to other game genres with contrasting themes and mechanisms.

5.4.2 Future Work

One potential research direction is haptic feedback: game developers could facilitate navigation or represent audio cues for varying distances by utilizing vibration. Another area of focus is the improvement of the Audio-Aim-Guidance. For example, researchers could evaluate the speed and accuracy of target acquisition for VI players in comparison to non-disabled players. Additionally, it would be interesting to explore the impact of audio cues across a broader range of game genres, such as puzzles or racing games, to assess the effectiveness of audio cues in diverse contexts.
Moreover, other fields of Human-Computer Interaction could be considered, such as Robotics or VR/AR technologies - applying the AOI mechanism to real-world scenarios may be beneficial. For instance, by equipping VI participants with a camera or AR glasses, an application could scan for obstacles and calculate distances - followed by sound feedback according to the position and kind of obstacle.

6 CONCLUSION

This study created a 3D action-adventure prototype to implement optimized sound design and sound representation techniques and test them on study participants. The goal was to strengthen the inclusion of players with sensory disabilities to non-disabled players, and to find key characteristics in sound design to improve inclusiveness. The main findings in this study are as follows: 1) Implementing the components from Table 1 results in a similar game experience between visually impaired and non-disabled players in the 3D action-adventure game Tap Tone. 2) The components lead to an equalization of the game performance. 3) The beneficial characteristics of the components were revealed and then discussed. Overall, this study has demonstrated a significant improvement and enhancement of inclusion between VI, DHH, and Non-disabled players. The successful participation of blind players in the game and their ability to reach the same goal in a similar time as non-disabled players indicate the positive impact of the developed audio cues. However, numerous areas could still be further explored and improved to promote greater inclusion for individuals with sensory disabilities. Future studies could focus on enhancing the haptic feedback, refining the Audio-Aim-Guidance mechanism, and investigating the effectiveness of audio cues in a broader range of game genres. With continued research and development, it is possible to create more accessible and inclusive gaming experiences for individuals with diverse disabilities.

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This study aimed to explore sound design and sound representation techniques to strengthen the inclusion of players with sensory disabilities alongside non-disabled players. Additionally, it aimed to identify characteristics in inclusiveness components for video games. Tap Tone is a 3D action-adventure prototype with iteratively improved inclusiveness components based on research and requirements analyses. Twenty-five participants were recruited for user tests and divided into four groups: 1) non-disabled, 2) vision impaired, 3) deaf and hard of hearing, and 4) blindfolded players. Data were collected with a questionnaire and saved in-game data. The data was analyzed using statistical methods, including ANOVA and a t-test. Results indicate that the experience for deaf and hard of hearing is significantly different from the groups vision impaired and non-disabled. The results indicate similarities in experience for non-disabled and vision impaired players. Moreover, the player performance indicates similarities between the groups non-disabled, vision impaired and deaf and hard of hearing. Finally, the study identified and discussed key characteristics of the inclusiveness components.

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Sound Design, Audio Cues, Video Games, Inclusiveness, Visual Impairment, Deaf and Hard of Hearing
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Denna studie syftade till att utforska ljuddesign och ljudrepresentationstekniker för att stärka inkluderingen av spelare med sensoriska funktionshinder tillsammans med icke-handikappade spelare. Dessutom syftade det till att identifiera egenskaper i inkluderande komponenter för videospel. Tap Tone är en prototyp av ett 3D-action-äventyrsspel med stegvist förbättrande inkluderingskomponenter baserade på forskning och kravanalyser. Tjugofem deltagare rekryterades för användartester och delades in i fyra grupper: 1) icke-handikappade, 2) synskadade, 3) döva och hörselskadade och 4) spelare med ögonbindel. Data samlades in med ett frågeformulär och data sparad genom spelet. Datan var analyserad med hjälp av statistiska metoder, inklusive ANOVA och ett t-test. Resultaten tyder på att upplevelsen för döva och hörselskadade skiljer sig signifikant från grupperna med synskada och icke-handikappade. Resultaten indikerar likheter i erfarenhet för icke-handikappade och synskadade spelare. Dessutom indikerar spelarens prestation likheter mellan grupperna icke-handikappade, synskadade och döva och hörselskadade. Slutligen identifierade och diskuterade studien nyckelegenskaper hos de inkluderande komponenterna.

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