ACCESSIBILITY OF SHOOTING TASK FOR BLIND AND VISUALLY IMPAIRED: A SONIFICATION METHOD COMPARISON

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ABSTRACT

Access to ordinary sports clubs or video games is limited for blind and visually impaired people (BVI) which reduces mixed ability practices and social inclusion. To adapt shooting video games and sports to BVI, we analyzed the literature to find sonification methods able to support targeting tasks. We identified four convenient methods ("Pitch Only", "Tempo & Pitch", "Tempo & Binary Pitch", "Chroma, Beats & Roughness") outcoming from other application fields such as medical assistance, navigation, or photography. To determine the best suitable sonification for shooting contexts, we carried out a within subject experiment in a 3D virtual reality environment. 24 sighted participants were asked to shoot as fast and accurately as possible on invisible targets, guided by sonic feedback only. With future mixed ability practices in mind, sighted participant's performances were also evaluated through a visual control condition. Results showed that participants were shooting faster in the visual condition, but more accurately in the audio-only conditions. "Chroma, Beats & Roughness" sonification lead to slower aiming time and more mentally demanding efforts than the three other methods. Analyses finally suggest that participants preferred to associate both pitch and tempo. Lastly, future participation of BVI persons will allow to deepen the results.

1. INTRODUCTION

Leisure activities are not just sources of entertainment and relaxation, they significantly impact social connections and overall well-being [1]. However, blind and visually impaired (BVI) individuals face unique challenges in accessing and participating in these activities, such as sports and video games, higlighting the pressing need for inclusive design solutions to ensure equal participation and enjoyment for all.

Parasports, which are sports for individuals with physical or intellectual disabilities, include 28 Paralympic sports sanctioned by the International Paralympic Committee (IPC). Of these, 12 are accessible to BVI individuals, along with six additional sports listed by the International Blind Sports Federation (ISBA). These include blind football, torball, shooting, and swimming, which use special equipment like sonic balls and audio aiming systems or require sighted guides. Adapted clubs provide this equipment, but their numbers and distribution are limited compared to regular clubs, posing additional obstacles to participation.

Figure 1: Participant, standing up, aiming with a controller in virtual reality

Similar challenges exist in mainstream video games, which are generally not accessible to disabled players. Although recent games like *The Last of Us 2*, *Forza Motorsport*, *Mortal Kombat*, *God of War*, and *Spider-Man 2* have been praised for innovative accessibility features (e.g., high contrast, screen readers, and navigational aids) at events like the Game Awards [1], most video games require BVI players to adapt themselves by developing strategies such as colliding with obstacles to map a room [2]. BVI players can also turn to audio games designed specifically for them, relying mainly on sound and haptic feedback [3, 4], but the selection is limited [2] and often does not appeal to able-bodied individuals, leading to increased social exclusion. Moreover, a survey by Andrade et al. [5] suggests that disabled gamers wish to play the same games as able-bodied individuals.

This research aims to improve access to shooting sports in regular clubs and shooting games to encourage mixed practices between sighted, partially sighted, and blind people. Our primary objective is to develop sonification techniques that convert visual information into sound [6] to facilitate the aiming process. Although both activities involve aiming, they have different constraints. In

[1]https://thegameawards.com/nominees/innovation-in-accessibility
[2]https://www.audiogames.net/list-games/

sports, shooting requires high accuracy and speed, with generally static targets. In video games, targets can be mobile and multiple, with aiming assisted by interactive aids, requiring less precision but still demanding speed to eliminate enemies before they hit the player.

Existing sonification methods in shooting sports [3] and video games like *Sea of Thieves* [4] use different parameters such as pitch, tempo, and stereo to guide shots. However, it is unclear which technique is most suitable for this task. Our goal is to evaluate the effectiveness of various existing methods in different contexts, focusing on their performance in shooting situations for both visually impaired and sighted individuals.

2. RELATED WORK

2.1. Accessibility and sonification in sports

The development of accessibility tools allows people with disabilities to practice various everyday tasks independently and promotes their social inclusion [7]. The majority of studies focus on navigational aids [8] for indoor and outdoor use, but there is also research more specialised in leisure [9].

A few studies aimed to improve the accessibility of adapted sports like in blind football where Mieda *et al.* [10] focused on the reaction time of blind players to identify the direction of a sound. Yandun *et al.* proposed a sound-emitting football cages that allow BVI players to practice shooting [11]. On the other hand, some research were dedicated to the accessibility of new disciplines to BVI, such as badminton using drones [12].

Although sound feedback is often used in studies for BVI, it can also be used to improve the sporting performance of sighted people. In several research concerning cycling, running or rowing [13], sound feedback is used to sonify movement, athlete or partner's heartbeat using sound parameters such as pitch, loudness, tempo or spatialized sounds.

2.2. Accessibility in video games

Research in video games for BVI individuals is mainly divided into two categories: creating audio games specifically for BVI users, and adapting existing games for accessibility.

The first category focuses on developing games that rely on audio and haptic feedback. For example, Miller et al. [3] created *Finger Dance*, a rhythm game where players press keys in response to audio cues. Archambault et al. [14] used their *TiM* platform to develop various game genres with sound and tactile feedback. Matsuo et al. [15] created an action RPG that can be played using either a screen or a tactile display.

The second category focuses on adapting existing games for BVI users. Nair et al. [16] proposed a method for exploring game environments using audio cues. Swaminathan et al. [17] developed a toolkit with spatial audio for navigation. Research also includes creating auditory guidance for driving games [18] and first person shooter like *Terraformers* [19]. In *Blind Hero* [4], visual notes were replaced with haptic feedback.

This overview in sports and video games shows a lack of research on the topic of shooting sport and shooting video games. Therefore, we extended our literature research to auditory guidance in pointing task in any context using a systematic approach.

[3] `https://britishblindsport.org.uk/az/shooting`
[4] `https://bit.ly/3vAhBYe`

3. SYSTEMATIC LITERATURE REVIEW ON AUDITORY GUIDANCE IN POINTING TASKS

3.1. Methodology

This section explains the methodology and selection process of this literature review. It mainly focuses on the auditory feedback used to help a user to aim at the center of a target with and without visuals.

This systematic literature review was conducted in February 2023. Research questions and keywords were first established and refined as papers related to our study were found. This research was performed on several databases using the keywords defined previously to narrow our results. To keep articles that would be relevant to our study and future experiments, inclusion and exclusion criteria were defined. Finally, the papers were reviewed, analyzed and the results summarized in the next section.

Search Strategy : Papers were retrieved from the following databases: Google Scholar, Scopus, Web Of Science and PubMed. Terms used were divided in 2 categories, words related to the task: *Guidance*, *Target*, *Shooting*, *Fitts*, *Pointing*, *Pursuit* and words related to the type of feedback wanted: *Audio*, *Auditory*, *Sound*, *Non-visual*, *Sonification*.

Inclusion criteria : 1. Use of sound feedback to provide information on location or distance from a target. 2. Use of sound feedback to guide a pointer, tool, hand, or orient someone toward a target or point of interest. 3. Sufficient information on the sound feedback design.

Exclusion criteria : 1. Studies not written in English. 2. Inaccessible studies. 3. Duplicate studies. 4. Insufficient information on sound feedback for reproduction. 5. Sound feedback not providing distance or position information of the cursor relative to a target or point of interest.

Query results : From the keywords search criteria, a total of 1286 articles were retrieved. After a first and second stage of sorting based on title and abstract, 1171 articles were excluded, and after reviewing the remaining 115 articles, only 13 were retained as the 102 left did not match the topic of our research.

3.2. Results

While our study's goal is the accessibility of shooting video games and sports for visually impaired and blind people, our literature review used generic term to find existing sonification methods for an aiming task. This led to gather articles with a wide range of fields such as audio guidance, medical, navigation, micro-guidance and others.

Fundamental research : We refer as fundamental research, articles that mainly focuses on the study of sound perception and sonification performances.

Parseihian *et al.* [20] evaluate several sonification methods to guide a user toward a target on a line. They split those methods into 3 categories: strategies without reference, strategies with reference, strategies with reference and zoom effect. Their results indicates that some strategies such as multi-band frequency modulation (MBFM), pitch or tempo strategies are generally effective regardless of task type, whereas "strategies with references" may vary depending on the task; therefore, a sound designer can choose a suitable sonification strategy based on task requirements and predicted performance outcomes, such as using MBFM for precise and fast guidance or FS for tasks with high precision and no time constraints.

Following the process of the previous study, Kantan [21] compares musical strategies with non-musical strategies on 1D guidance, taking in account the aesthetics of the sound feedback in the user's performances. While musical strategies led to longer acquisition time, no significant effect was found between those categories in terms of precision.

In [22], Gao *et al.* attempt to compensate for poor human sound perception in elevation. They designed and compared multiple mappings of pitch on the Y-axis to help a user find a visual target among distractors with an azimuth sonification strategy using tempo and spatial auditory cues rendered by generic HRTFs. Their results showed that the Binary relative Elevation mapping was effective in precision, acquisition time and required the least overall cognitive load.

Medical : This category refers to research with medical purpose, usually to assist a surgeon during an operation.

Hansen *et al.* [23] present a sonification method assisting the surgeon to follow a cutting line on a liver without relying on the visual aids on screen. To do so, 3 zones are defined on both sides of the cutting line, the safe zone, the warning zone and the external zone. Each zone emits different types of sound feedback to help the surgeon to rectify its trajectory by giving the distance and position information of the cutting knife. The results indicated improved precision when following the cutting line and reduced reliance on the screen when utilizing audio feedback.

Miljic *et al.* [24] presents an audio feedback system to give a positional guidance in real-time to a surgeon during a brainstem implant. In their study they aim to compare 3 sonification methods in a 3D environment: a method combining pitch, loudness and tempo, a method using a signal-to-noise sonification according to the distance to the target and a method using only tempo according to the distance. No experimental results were presented in the paper.

In [25], Ziemer *et al.* present a two-dimensional guidance sonification method design to guide surgeon. This method was designed to give distance and direction information to the user using several sound parameters: chroma with the use of Shepard Tones, beats and roughness. Results showed that despite the navigation taking longer time, this method could help sighted persons to finds invisible targets while not significantly increase subjective mental workload.

Navigation : While most of the navigation and sound localization papers were rejected as they were only using discrete sound feedback with spatialization technique to guide users, some research were kept because their experiment task or the proposed sonification method could be applied to an aiming task.

In order to help visually impaired persons to find an object in a room, Chung *et al.* [26] compared guidance performances between haptic feedback with vibrations, audio feedback with beeping sound and multimodal feedback combining both vibrations and beeping sounds with and without stereo. To do so, users had to point at a target around them using the feedback given as fast as they could. Their results showed that beeping sounds with or without haptic and with stereo could help finding a target location efficiently.

Dadamis *et al.* [27] evaluate the effectiveness of several audio feedback to attract the user's attention towards a point of interest in a landscape. They show that while beeping sounds can help targeting small target, it slows down the user on larger target compared to methods using 3D audio hints.

Micro-guidance : We label micro-guidance, research that focused on guiding the user's hand toward or on an object.

Ménélas *et al.* [28] compares haptic, audio and multimodal feedback to guide a hand in an target acquisition task amongst distractors in a 3D environment using a Virtuose 6 DoD device. Results showed that haptic attraction and multimodal feedback were suited to identify a target amongst other. Participants also noted the difficulty to clearly understand when the audio modulations were at their highest.

Guarese *et al.* [29] aimed at creating a sonification method to help visually impaired people to locate an object and guide the hand towards it. They designed 7 methods to guide the user on a 2D plane with a computer mouse. BVI participants showed better acquisition time than sighted participants, musically literate participants also performed better both in acquisition time and precision than non-musical participants.

Following informal test on a sonification method using pitch and tempo with visually impaired persons, Coughlan *et al.* [30] designed a guidance system using only verbal instructions to help a BVI user exploring a small object and guide them toward its points of interests.

Others : Much research focuses on the use of sound feedback to substitute the sight in low vision condition such as tracking a moving target with a handheld camera. Seko *et al.* [31] tries to tackle this problem using sonification providing feedback to keep the target in the frame while following it. Their design uses several sound attribute such as intensity, pitch and spatialization to warn the camera operator of the distance from the target.

Konttinen *et al.* [32] studied the effects of auditory feedback on the performances of military shooter and retention of skill over 4-weeks. 3 groups were tested: a control group without training, one group with training without feedback and a group with audio feedback during half of their block. After a 4-week training, the group trained with auditory feedback showed better retention over time than the other groups.

3.3. Conclusion

Following this systematic review, it is difficult to select the most efficient method for a shooting task. Indeed, each context of use is different with task taking place in one to three dimensions, environment size from a line on a screen to a target in a sphere around the user. This results to very different precision and aiming duration performances.

Among the 13 articles, 45 different methods were identified. From the sonification methods listed, 4 methods[5] were selected. The first method is based on pitch alone. Not only pitch is the most used parameter in the literature (see Table 1), it is also the parameter currently used in shooting competition [35]. It allowed us to take it as a baseline of sonification strategies to compare with other existing strategies. Although the tempo was identified as the second most frequently utilized parameter, the combination of pitch and tempo presented an interesting structure by separating the vertical and horizontal axis. Two methods were kept from [22]. The first one, Unsigned relative Elevation (UE), uses a similar approach as the pitch only method while adding tempo on the x-axis and Binary relative Elevation (BE) mapping showed good overall performances in the paper. Finally, the last method was selected based on its design sonifying each direction (top, bottom, left and right) with a different sound parameter using the chroma, beats and roughness of the sound [25].

[5] `https://bit.ly/3xpo5cO`

Sound Parameters	Appearance in articles	Usage in a method
Pitch [32, 20, 21, 22, 29]	5	11
Tempo [20, 24, 27, 33]	4	4
Loudness [20, 21]	2	3
Brightness [20, 21]	2	3
Harmonicity [20, 21]	3	5
Beatings [20, 21]	2	3
Synchronicity [20, 21]	2	3
Tonality/Noisiness [24]	1	1
Verbal [30]	1	1
Pitch & Tempo [22, 23, 29]	3	7
Loudness & Tempo [28]	1	1
Pitch & Loudness [31]	1	1
Pitch, Loudness & Tempo [24]	1	1
Chroma, Beats & Roughness [25]	1	1
Chroma, Beats, Roughness, Brightness & Fullness[34]	1	1
Spatial Audio [22, 28, 30]	3	10
Stereo [24, 26, 29]	3	4

Table 1: Single and combined sound parameters appearance in the literature and usage count in sonification methods

4. SONIFICATION METHODS

Pitch Only (PO) : The first method is coming from the system currently in place in world competitions of adapted shooting sports [35]. It uses only the variation in pitch. The closer the user gets to the center, the higher the sound becomes from 200 Hz to 2000 Hz. In order to provide a similar contrast to the visual black center of a real target, a 600 Hz reference tone informs the shooter that they have reached the center of the invisible target. This method only informs the user of the distance to the center.

Tempo and Pitch (TP) : This second method inspired by the Unsigned relative Elevation method from Gao *et al.* [22] uses two sound parameters to provide both distance and position information. On the vertical axis, a method similar to pitch only is used. On the horizontal axis, the data is linked to the on-off repetition rate of the sound. It becomes increasingly rapid as the cursor approaches the center of the target from a beep every second to every 100 ms.

Tempo and Binary Pitch (TBP) : This method inspired by the Binary relative Elevation method from Gao *et al.*[22] uses two sound parameters to provide both distance and position information. On the vertical axis, above the center of the target a low pitch of 200 Hz is displayed, under the center of the target a high pitch of 2000 Hz is displayed. On the horizontal axis, as in the previous method, the data is linked to the on-off repetition rate of the sound, which becomes increasingly rapid as the cursor approaches the center of the target.

Chroma, Beats and Roughness (CBR) : This sonification, from Ziemer *et al.* [25], uses multiple properties of sound to guide the user to a given point in surgery. This method is interesting since it sonifies each part of the target (top, bottom, right and left) in a different way, giving a more precise idea of the direction required to get to the center of the target.

To do so, this method uses Shepard tone, acoustic beats and the roughness quality of the sound. The horizontal axis is sonified so that the user hears a range of Shepard sounds rising at a slower rate as they approach the center of the target from the left and falling at a faster rate as they move away from the center to the right. The vertical axis uses the beat and roughness of the sound, so that as the user approaches the target from above, the beat becomes slower and slower. As the user approaches from below, the sound becomes less and less rough. As the user passes over the horizontal line, a clicking noise can be heard to help find the correct height. When the shooter is in the center of the target, the volume and pitch of the sound remain constant and a white noise is layered on top of the other sounds to contrast.

Sonification Design Adjustments : Some adjustments were implemented on TP and TBP to align with the design of the other two methods that display a contrasting sound at the center of the target. Therefore, contrasting sounds were added so that a 600 Hz frequency is heard when the aim reaches the correct ordinate value and the tempo becomes still when reaching the correct abscissa value. Thus, at the center of the target, there is a continuous 600 Hz reference tone. Moreover, spatialization was removed from TP and TBP in order to avoid introducing additional variables that could potentially affect the results.

5. EXPERIMENT

This study compares the guidance performance of 4 sonification methods in a shooting context on BVI and sighted people in VR. We want to determine which sonification method gives the best guidance performance in terms of speed and accuracy, as well as observe whether aiming performance in audio only can come close to visual aiming performance.

5.1. Hypotheses

The following hypotheses were formulated:

H1: The **number of sound parameters** on which the guidance method is based **reduces shooting time and increases accuracy**.

H2: The **number of sound parameters** on which the guidance method is based **increases the cognitive load**.

H3: **Sighted** participants will have **better overall performances** in both speed and precision in **visual condition than in the auditory conditions**.

5.2. Experimental Method

Participants : 24 sighted participants took part in the experiment [5 women and 19 men; age: min. 22; max. 30]. All participants underwent an audiogram test beforehand. All participated voluntarily and signed a consent form before the experiment.

Stimuli and Apparatus : The experiment was carried out on an HTC Vive Pro with only one controller. Participants were asked to stand in the center of the room on a mark on the floor before putting on the VR headset. The application was developed on Unity 2020.3.11f1d, using Steam VR on a desktop computer with the following specifications: Intel Xeon W2135 CPU with Quadro RTX 4000 graphics card and 32GB RAM. Sounds were produced in the headset using PureData 0.53-2 and LibPd Unity Integration scripts to use Pd patches in Unity. The sounds were synthesized in real time using the strategies described above. It was asked to the participant to set the volume at a comfortable level during the hands-on phase.

Procedure : Participants shot at visible and invisible targets placed in predefined locations in front of them. Each sighted participant completed 5 blocks (1 visual and 4 audio), each consisting of a familiarization, training, and experimentation phase.

During the familiarization phase, a target appeared in front of the participants, allowing them to get to grips with the visual aim or the sonification method. In the visual condition, the target is visible and a red pointer appears where the users are aiming to help them understand how the virtual gun's sight works. In the audio only conditions, the target is invisible and sound feedback is provided to familiarize the user with the sonification method for the current block. To move on to training, the participants were asked to shoot at the center of the target to ensure that they hear the characteristic sounds of the center for each method at least once.

The training phase involved shooting at 6 targets positioned in a circle, 50 cm from the center and 1.4 meters high, spaced 60 degrees apart (see Figure 2). Participants could take breaks between shots (successful or unsuccessful) and had to hit the center of 3 targets to proceed to the next phase.

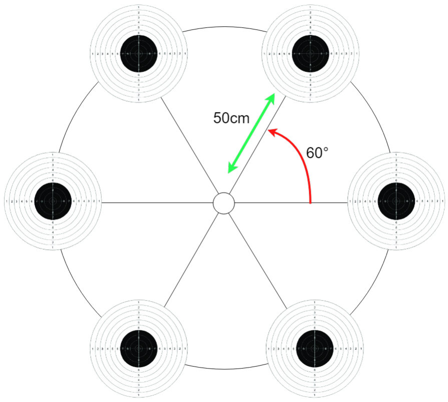

Figure 2: Targets' predetermined positions placed in circle 50 cm away from the center

The experimentation phase mirrored the training phase but required 6 shots regardless of the result.

The visual condition was always first, and auditory conditions were counterbalanced. Each participant completed 5 blocks of 6 shots, totaling 30 shots per session. They filled out questionnaires at the start, end of each block, and end of the experiment to provide feedback and rest.

The experiment lasted between one and one and a half hours.

6. RESULTS

For each participant, at each trial, the accuracy of the shots in terms of angular error, the aiming time and trajectory were recorded. Participants were asked to complete a NASA-TLX and System Usability Scale (SUS) questionnaire after each block to assess the mental load and usability of each method.

These data were analyzed using a Friedmann test. Data were considered significant when the p-value was less than or equal to 0.05. Significant differences between aiming methods were analyzed using a Nemenyi post-hoc test.

6.1. Accuracy

The visual condition led to a median accuracy of 0.83° (IQR 1: 0.467; IQR 3: 1.307). The auditory conditions led to accuracies of 0.51° (IQR 1 : 0.315; IQR 3 : 0.704) with the PO method, 0.46° (IQR 1 : 0.331; IQR 3 : 0.686) with the TP method, 0.62° (IQR 1 : 0.394; IQR 3 : 0.874) with the TBP method and 0.54° (IQR 1 : 0.36; IQR 3 : 0.7) with the CBR method. Statistical analysis showed that there was an effect of the strategies (p-value < 0.001).

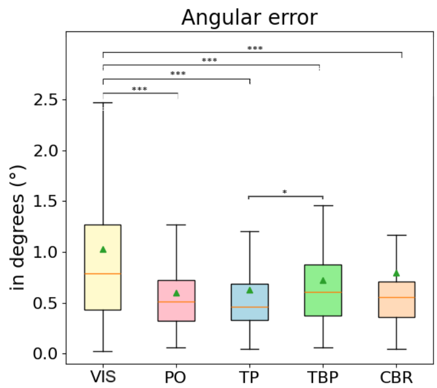

Figure 3: Aiming duration in seconds by aiming method (* = p-value <= 0.01; ** = p-value <= 0.05; *** = p-value <= 0.001)

Post-hoc analyses showed that all the audio methods led to more accurate shots than visual aiming (p-value < 0.001).

6.2. Aiming duration

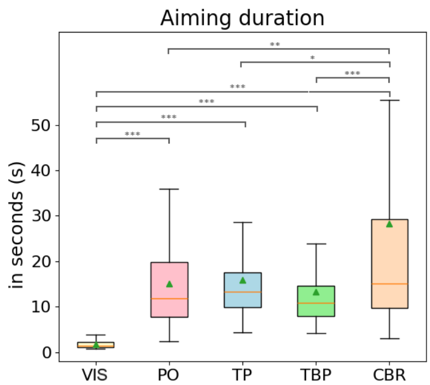

Figure 4: Aiming duration by aiming method (* = p-value <= 0.01 ; ** = p-value <= 0.05 ; *** = p-value <= 0.001)

The visual condition led to a median aiming time of 1.52s (IQR 1: 1.12; IQR 3: 2.30). The auditory conditions led to median aiming times of 12.16s (IQR 1 : 7.92; IQR 3 : 21.07) with the PO method, 13.31s (IQR 1 : 9.88; IQR 3 : 18.29) with the TP method, 10.9s (IQR 1 : 8.03; IQR 3 : 15.41) with the TBP method and 15.79s (IQR 1 : 10.08; IQR 3 : 29.57) with the CBR method. Statistical analysis shows that there is an effect of the strategies ($p < 0.001$). Post-hoc analyses showed that the visual method led to faster shots than audio aiming (p-value < 0.001). They also showed significant differences between PO and CBR methods (p-value < 0.05) and between TBP and CBR (p-value < 0.001). CBR therefore leads to slower shooting performance than the PO and TP methods.

6.3. Cognitive load & Usability

The NASA-TLX [36] questionnaire is used to assess the mental load of a task. It consists of questions asking the participant to

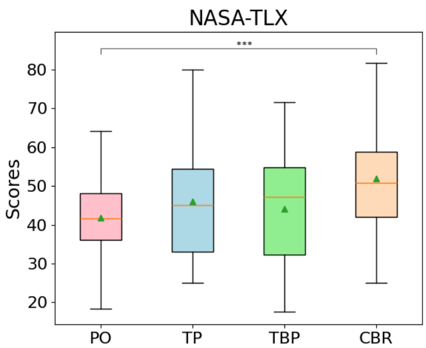

Figure 5: NASA-TLX scores by audio targeting method (* = p-value <= 0.01 ; ** = p-value <= 0.05 ; *** = p-value <= 0.001)

rate various affirmations on a scale from 0 to 100. Maximum values correspond to a higher mental load and minimum values to a lower mental load. The PO method obtained the lowest mean score (41.75), followed by the TBP method (44.14) and TP (46.12). CBR obtained the highest mean score (51.99), indicating a greater mental load when used.

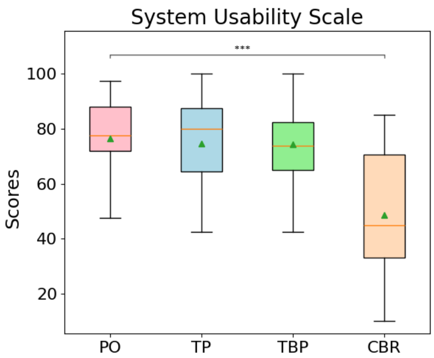

Figure 6: SUS scores by audio targeting method (* = p-value <= 0.01 ; ** = p-value <= 0.05 ; *** = p-value <= 0.001)

The SUS [37] questionnaire assesses the usability of a system using questions based on a Likert scale with values ranging from "Strongly disagree" to "Strongly agree". The PO method obtained the highest average usability score (76.56), followed by the TBP (74.48) and TP (74.58) methods, and finally CBR, which obtained the lowest average usability score (48.75).

6.4. Qualitative results

After each block, the participants completed a questionnaire on a computer. The aim of these questionnaires was to collect feedback on the difficulties encountered when using the guidance methods, the strategies used to find the center of the targets and the preferences between the different sonification methods.

Strategies : Various searching strategies were put in place to find the center of the targets according to the characteristics of each of the sonification methods.

For PO, participants employed various search strategies. Some scanned the scene, while others used circular or staircase patterns to approach the center. Despite the lack of distinct sounds between axes, one participant employed a methodical approach, searching axis by axis for the highest-pitched sound. Another participant moved away from the target to better discern pitch differences. Most strategies involved quickly approaching the area and refining the search for the center.

For the TP and TBP methods, participants generally opted to search vertically with the pitch and then horizontally with the tempo. A few participants tried to find the right tempo first and then the right pitch, while others tried to find the nearest axis first without preference.

Most of the participants implemented a similar strategy for CBR by first finding the right pitch with the clicking sound and then the right orientation with the white noise. However, some participants used the rough sounds to position themselves vertically and then found the center by moving horizontally.

Difficulties : Participants encountered three difficulties while using PO, the lack of indication of which direction to take and the absence of axes separation made it difficult to understand which way to move. Participants reported having trouble with the final adjustments needed to find the precise center of the target.

TP and TBP methods generally created fewer difficulties when used, but some participants struggled in maintaining their aim on an axis when searching for the second one. Some difficulties appeared when trying to clearly distinguishing certain sounds such as the differences between the three notes in TBP.

CBR, being a more complex sonification method, posed more difficulties for the participants. In fact, this method generally required participants to concentrate and remember the various sound parameters in order to direct themselves, in particular the Shepard scales.

Some participants also noted auditory fatigue and sometimes annoyance when using these methods over long sessions.

Preferences : In addition to the participants' preferences, a ranking of the sonification methods was requested in order to find out which method was most appreciated.

TP was the most popular method followed by TBP for the simplicity of the sound feedback and the design separating the two axes the participants to focus on one parameter at a time to find one axis after the other. Many of the participants appreciated the simplicity of TBP's sounds, which allowed them to quickly know which direction to go in vertically thanks to the three tones.

PO was considered rather complicated to guide oneself due to the lack of differentiation of the axes. However, the simplicity of the method was appreciated. The pitch of the sound was also noted to be annoying and tiring at times.

Finally, CBR was the method least appreciated for its complexity, although the white noise in the center and the clicking sound on the vertical axis were found to be very useful for contrasting and finding the center.

7. DISCUSSION

While no significant effect was found between methods using one (PO) and two parameters (TP and TBP) in accuracy and speed, CBR, which used three parameters, led to slower shots with similar accuracy. Thus, H1 is not verified. Participant's feedback also showed a preference for two-parameter techniques, especially TP, which performed as well as the single-parameter PO method.

CBR was rated as the most mentally demanding method, but no significant effect was found between one (PO) and two-parameter methods (TP and TBP). The complexity of CBR's sounds may have contributed to higher mental workload, as participants had to remember sound modulations relative to the target center. This, along with the "moving sounds" during aiming, may have caused confusion and increased mental load, so H2 is also not verified. Future research should explore the cognitive effects of sound parameters individually and in combination.

Overall, visual guidance led to faster aiming times, while auditory guidance resulted in more accurate shots, partially verifying H3. This could be due to the distinct sound at the target center, prompting participants to prioritize accuracy over speed. These findings suggest that audio can benefit sighted individuals in precision tasks and support visual aiming as shown in [32]. Further investigation into the impact of central contrasting sounds on speed and precision trade-offs is warranted.

These results advocate for simple parameter strategies and axis distinctions for precision and speed tasks. Future studies will focus on improving aiming speed by exploring various sound parameters from the literature (see Table 1).

Limitations : However, our current work has limitations that we can address in the future. Firstly, although our study aimed to make shooting tasks accessible to blind and visually impaired (BVI) individuals, it was conducted only with sighted participants on invisible targets. This provides relevant design insights for sighted users, but BVI participants' performances and preferences might differ.

Additionally, the study only examined four sonification methods from the literature. While other methods with diverse sound parameters might offer better performance, a limited selection was chosen to avoid lengthy and fatiguing experiments for participants.

Lastly, adjustments were made to these four sonification methods to even their design, such as adding contrasting sounds. However, these changes were not uniformly applied across all methods due to differing sound parameters. For example, a 600 Hz tone was added at the target center for pitch-based methods, while a white noise was used in CBR in alignment with the referenced literature. These design differences could be confounding variables, as performance might be influenced by these choices rather than the sonification method itself. Moreover, if the precision of the auditory condition comes from the central distinguishable sound, it can also be implemented for the visual display (e.g., adding a central line or highlight the center when the target is in line). Then, the different accuracies may not come from different modalities, but it can depend on whether there's a presence of a specific design component or not. Future work could explore how these design components affect participants' performances.

8. CONCLUSION

In this paper, we compared, in a VR shooting context, the performances of 4 sonification methods coming from a literature review on sonification for aiming. Precision, speed, cognitive, and usability were evaluated. Results showed no significant effect on precision. However, the method CBR, relying on three auditory parameters, lead to slower aiming performances, higher cognitive load, and lower usability score than other sonification methods. While the sonification methods lead to overall slower aiming speed than in the visual condition, they also lead to more accurate shots which supports the idea of the benefits of audio guidance systems even to sighted users. As precision performances proved satisfactory for our shooting context, further investigations will focus on improving aiming speed performances. This experiment is currently being evaluated with BVI participants. We aim to observe BVI's performances in audio condition compared to the visual condition of sighted users to verify if a mixed practice in activities like competitive video games can currently be considered.

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