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Level-Up! Comparing accessibility features based on gameplay performance.

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Abstract: This study examined the impact of accessibility cues on hearing and non-hearing players' performance in a 3D, third-person shooter video game. The intent was to resolve the debate about whether accessibility features unfairly lessen the difficulty of video games for hearing players. In this study, players completed the video game with three accessibility cue conditions (visual, haptic, both) and were assigned to one of two audio conditions (audio, no audio). Hard-of-Hearing (HOH) participants played the video game under all three cue conditions. Performance data indicated that accessibility cues helped players without audio without affording an unfair advantage to those with audio. Qualitative data indicated that participants' beliefs about the cues aligned with the popular—but inaccurate—belief that accessibility cues afforded them an advantage. This research is a first step in examining accessibility cues in the context of video games. The results can be applied to video game design as well as to other fields that use cues to convey information—such as human perception—and as a method for designing cues for training people in the medical, aerospace, and education fields.

Keywords: videogames, accessibility, haptics.

1. Introduction

The experience of watching movies in the theatre has become a modern cultural norm that provides both entertainment and meaningful social interaction. However, a film with important dialogue but no audio or captioning would not be well-received. This scenario illustrates the experiences of Deaf and Hard-of-Hearing (HOH) people any time they visit a public theatre. People probably would not pay for this kind of experience.

Hearing loss greater than 40 decibels (i.e., difficulty understanding speech) is experienced by at least 466 million people around the world. Although hearing loss is disproportionately present among individuals 65 and older (WHO, 2020) it can happen to anyone, regardless of age. People who are Deaf and HOH want to share the same experiences as everyone else, but this can be difficult when human-made environments fail to follow the principles of universal design. Universal design allows most people to use or experience a product without adaptation, no matter their age or abilities (Story et al., 1998; Story, 2001). Ideally, accessibility features are so well-integrated into the design of a product that they are seen as "normal" and inconspicuous

(Story, 2001). While universal designs are legally required for physical spaces, modern communications, and digital media (ADA, 1990; DOJ, 2010; FCC, 2010), no such requirements exist for non-speech accessibility features (e.g., sound effects, audio cues) in video games.

Some video game companies incorporate and share details about accessibility features through pre-release announcements. For example, Ubisoft (2019) tweeted a list of all the accessibility features included in Ghost Recon Breakpoint, including controller remapping, secondary audio and haptic cues, and user-adjusted visual contrast. Details on video game accessibility features are also spread independently through the gaming community in the form of accessibility-specific reviews (e.g., https://caniplaythat.com). Despite these efforts, many developers fail to implement accessibility features. In some instances, the failure to provide accessibility features has been taken up by members of the gaming community who produce game modifications (Bierre et al., 2005). These efforts require significant time and skill, placing undue burden on volunteers.

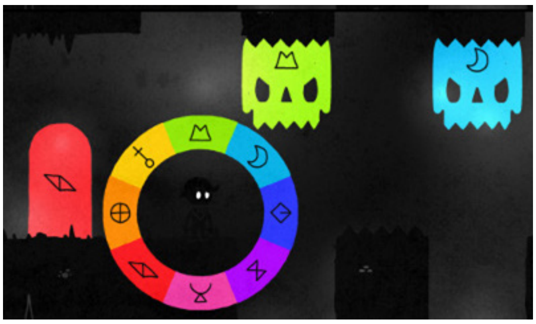
While advocates push for additional accessibility features in video games (Porter, 2014; Bierre et al., 2005), others resist due to concerns that accessibility features would lessen the difficulty of video games and reduce players' enjoyment (e.g., Metro UK, 2021). This paper reviews empirical evidence that supports the competing claims of each perspective: namely, whether accessibility features unduly help or hinder the players who choose to use them. We then report the results from an empirical study that was designed to test these hypotheses using a custom-designed video game that incorporated accessibility cues for Deaf and HOH players.

1.1. Accessibility in video games

Video games can be difficult for Deaf and HOH people to play because they often use auditory cues to convey important information. For example, a game may use footsteps to indicate an approaching enemy character or gunfire to signal an enemy's attack. These cues are easily missed by people who cannot hear the sounds or who are playing with the volume off. When auditory cues are the only means by which a display conveys important information, it significantly impacts some players' experience. Previous research has shown that removing sound associated with even a simple action—confirming a selection—increases players' reaction times and decreases their presence within the game world (Jørgensen, 2008). Developers who plan accessibility features from the start of the game create better products and can market their products to a broader audience (Powers, 2015).

Figure 1-left. Screen captures of Hue with visual accessibility features.

Figure 1-right. Screen captures of Hue without visual accessibility features.



Accessible video games ensure essential information is conveyed with a multi-cue display that spans two or more sensory modalities (Ng, Nesbitt, 2013; Barlet, Spohn, 2012; Ellis et al., 2020). For example, the game Hue has an option to add symbols that correlate with each colour (see

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Figure 1), providing important pattern information to those who cannot easily discriminate colours. Visual and haptic cues can also be used in this manner, such as when a player taking damage hears an audio groan alongside decrements in an on-screen health bar and a controller rumble (see Figure 2).

Figure 2. Screen capture from The Legend of Zelda: Breath of the Wild. Here, an auditory grunt and haptic rumble indicate that an enemy has been hit. Additional details about the intensity of the attack are available in a visual health bar (icons added to original screenshot).

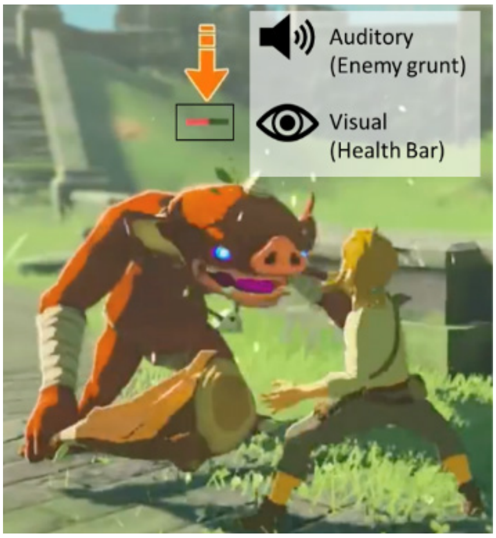
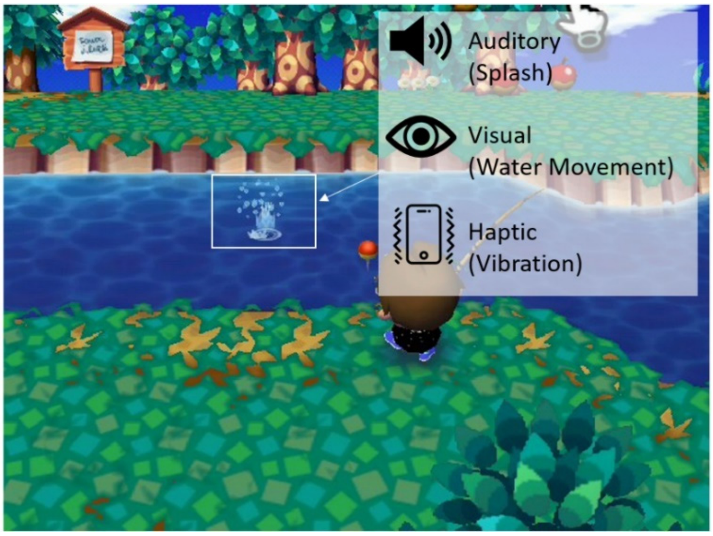


Figure 3. Screen capture of a fishing task in Animal Crossing. Here, an auditory splash, visual water movement, and a haptic pulse all indicate that the fish has bitten the line (icons added to original screenshot).



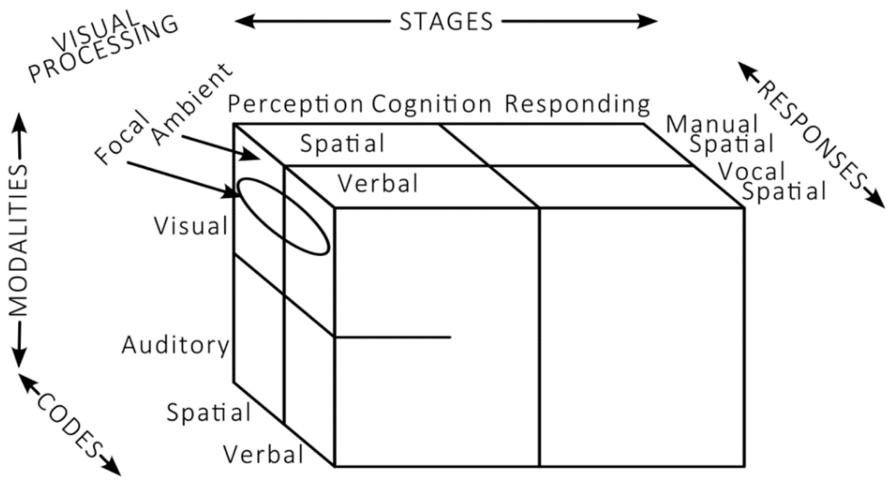
1.2. Multi-cue displays

There are three types of multi-cue display mappings: complementary, redundant, and conflicting displays (Ng, Nesbitt, 2013; Pao, Lawrence, 1998). Accessibility cues typically present as complimentary displays or redundant displays. Complementary displays use different sensory modalities to convey information with varying levels of detail (Ng, Nesbitt, 2013). For example, a game developer may use an auditory grunt and controller rumble to indicate that an enemy character is taking damage. Additional information about the extent of damage is indicated by a visual decrement in the enemy's health bar (see Figure 2). Redundant displays use different sensory modalities to convey information at similar levels of detail. For example, in a fishing game, a visual splash, a splashing sound, and a controller vibration all tell the player that a fish bit the line (see Figure 3). Intuitively, complimentary and redundant displays should increase task performance, increase users' confidence, and decrease their perceived workload (Ng, Nesbitt, 2013).

1.3. Multiple resource theory

While multi-cue displays provide a player with additional opportunities to identify relevant cues, they also create information-rich environments where people may struggle to attend to relevant information (Rosenholtz et. al., 2007). Wickens' (1980, 1991) multiple resource theory (see Figure 4) provides a useful framework for understanding the circumstances under which multi-cue displays can negatively impact performance. Multiple resource theory assumes that players' cognitive and perceptual abilities are limited by the amount and type of information they attend to, as well as when and how they attend to that information.

Figure 4. A graphical depiction of points of overlap in aspects of peoples' cognitive and perceptual resources (Wickens, 2008).



A person playing a video game must see (perception), think about (cognition), and respond to information. These stages of processing involve separate pools of resources and can be performed at the same time. For example, a player might notice a controller rumble (perception) while actively controlling their character (response) and planning their next move (cognition). Selective attention (Broadbent, 1958) allows a player to determine which information is perceived and considered for subsequent cognition and responding. It is informed by a player's experience: inexperienced players take a bottom-up approach by which attention is drawn to notable characteristics of the stimuli (e.g., motion; Navalpakkam, Itti, 2006), whereas experienced players can use a top-down strategy to constrain their attention to areas of importance that are identified based on previous knowledge (Navalpakkam, Itti, 2006; Soto et al., 2006). Therefore, players have varying degrees of control over when and how they attend to the different cues that are presented during gameplay.

Problems arise when multiple pieces of selected information occupy the same stage of processing. This is especially true when this information involves the same modality. For example, an auditory ping allows players to easily track the collection of items during a visually stimulating fight. A visual-only inventory, in contrast, would substantially impair gameplay by requiring a player to scan for acquired items while also attempting to track enemy locations. The superiority of auditory cues in visual environments has been demonstrated across a variety of contexts (e.g., Wickens, Sandry-Garza, Viulich, 1983). Similarly, studies suggest that haptic cues are equally or more beneficial in conveying information during visual tasks (Van Erp, Van Veen, 2001; Medeiros-Ward et al., 2010; Bovard et al., 2018; Sklar, Sarter, 1999). In addition, haptic cues have many benefits that make them a viable option for interfaces: they are transient, can capture attention with minimum intrusion, are omnidirectional, and can be presented in many locations on the body (Lu et al., 2011; Sklar, Sarter, 1999). Therefore, it is recommended that auditory or haptic cues be used to convey information in highly visual environments (for a review see Lu et al., 2011).

1.4. Multiple resource theory as a computational model

Wickens (2002) provides a computational model for predicting the degree to which additional information conflicts with a task's required cognitive or perceptual resources. In this model, overlapping resources are noted in a conflict matrix that represents the relative degree to which the resources cannot be shared. The resource demand of each task is modelled by a demand vector, which can be aggregated with the conflict matrix to yield a single total task interference value. This interference value can then be compared with other task interference values from other task configurations to make a relative judgement on which configurations have the highest resource conflict (and thereby, the lowest performance).

Third person shooter videogames require players to visually track and respond to many on-screen events. Players using sound (e.g., background music) must also listen for information about enemy locations (e.g., footprints) and successful attacks (e.g., groans). Players without access to sound cannot attend to auditory information of any kind, placing them at a distinct disadvantage. Therefore, videogames are highly visually demanding for both hearing and non-hearing players, and are moderately aurally demanding for players using sound.

Table 1. Resource conflicts predicted by Multiple Resource Theory (Wickens, 2002).

Additional Accessibility Cues	Total Conflict	HOH	Hearing
No cues	0.33	x	
Attending to visual cues	0.91	x	
Attending to haptic cues	1.03	x	
Attending to auditory cues	1.09		x
Attending to visual and haptic cues	1.43	x	
Attending to auditory and haptic cues	1.61		x
Attending to auditory and visual cues	1.49		x
Attending to auditory, visual, and haptic cues	2.02		x

Wickens' (2002) computational model offers clear predictions regarding the resource demands placed on players who need accessibility cues (e.g., HOH individuals) and those who can use but do not require them (i.e., hearing individuals). Contrary to intuition (e.g., Metro UK, 2021) and best practice (e.g., Ng, Nesbitt, 2013), Multiple Resource Theory suggests that hearing players who use accessibility cues act to their detriment by increasing their total cognitive load (see Table 1). The negative consequences of this cognitive load should be particularly pronounced under high workload conditions (i.e., when the videogame is especially hard; Wickens, 2002 Stanton et al., 1997).

1.5. Current study

The purpose of this study was to test the impact of accessibility cues on performance and to determine players' accessible cue preferences. We addressed these research questions within the context of a video game that used visual, auditory, and haptic directional cues to indicate the relative direction of a new oncoming enemy relative to the player. This game was primarily a visual experience that included some sound effects, such as firing weapons and groans following damage to the enemies or the player.

Multiple Resource Theory and the literature on redundant displays offered competing hypotheses regarding participant performance:

- H1A (Redundant Displays): Additional cues will act as a redundant display and improve or have no effect on performance.
- H1B (Multiple Resource Theory): Accessibility cues will improve the performance of players without audio; additional cues will act as a conflicting display and impair performance.

Table 2. Information about participants' gameplay habits.

Additional Accessibility Cues	Hearing	HOH
M (SD) hours weekly gameplay	15.6 (12.9)	9.2 (15.0)
N considering self "gamer"	28	2
Gaming platforms used		
None	4	1
PC	29	0
Console	26	0
Mobile phone	19	3
VR	7	0
Other	2	0

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2. Methodology

2.1. Participants

Thirty-nine hearing participants (16 females; Mage = 25.5) and 4 HOH participants (1 female; Mage = 33.5) were recruited from the Wichita State University campus community. Recruitment was conducted using the SONA experiment management system, recruitment flyers in newsletters, and word-of-mouth. Hearing participants received research credits, while HOH participants received a lab-themed mug. Information about participants' gameplay habits is presented in Table 2; gameplay information was unavailable from one hearing participant due to researcher error. This research complied with the American Psychological Association's code of ethics and was approved by the institutional review board at Wichita State University.

2.2. Third-person shooter videogame

Participants played a 3D, third-person shooter (TPS) videogame developed with the Unity game engine (Unity, 2019; source code is available through GitHub (https://github.com/ChaMP-Lab/SurvivalShooter.git). Players controlled a character trapped in a nightmare with stuffed animal zombies. The stuffed animals moved towards and attempted to harm the players' character. The players, in turn, evaded and eliminated the stuffed animals using a toy gun. Each experimental session lasted 60–80 minutes, which provided enough time for the players to meet their goal of completing a short tutorial and passing 20, two-minute levels of the game.

Each level started without any stuffed animals; new stuffed animals appeared randomly at pre-determined locations every three seconds until the game space contained 30 enemies. At this point, new stuffed animals would only appear as existing ones were eliminated. Players were incentivized to eliminate enemy characters through game elements: a visual score counter tracked kills, enemies groaned upon receiving damage and displayed a death animation when killed, and damage received by the player hindered their progress and increased the amount of time that they had to spend in the research session.

Figure 5. Participants' view of the play screen. The visual accessibility cue alerts the player to the direction of oncoming enemies.

Directional cues signalled approaching stuffed animals. These cues were deployed the first time each enemy crossed a predetermined threshold (see Figure 5) and were determined based on each stuffed animal's location relative to the player's character. Specifically, haptic cues vibrated the appropriate side of the controller; visual cues depicted directional arrows; and audio cues (a monster groan) were played to the appropriate side of the headphones. When enemies crossed the threshold at the same time, the cues were given one after the other. The same threshold that triggered a new-enemy-cue also served as a barrier to restrict the player's movement to the lower area of the world, affording them more horizontal than vertical freedom.

Players started each level with 100 hit points of health. Each time a stuffed animal touched the character, the attack dealt 10 hit points of damage. The character also shouted "ouch," the screen flashed red, and a health bar in the lower left corner was reduced by 10% of its initial size. When the player's health was fully depleted, the character lost one of three total lives. When a player lost a life, the level timer paused, and they waited on a 30-second loading screen. Once the game resumed, the health bar was restored to full size, but players had one fewer life icon next to the health bar. If the player lost all three lives, they proceeded to the next trial. The player's health and lives were restored at the start of each level.

Players used an Xbox One controller to interact with the game. The left analog joystick moved the character around the screen. The right analog joystick aimed the weapon, which could be fired with the right trigger button at the top of the controller. All other controls were disabled for this application. This controller configuration was selected for its prevalence in TPS videogames.

2.2.1. Difficulty manipulation

The difficulty of the videogame was manipulated at the start of each level by changing the enemy characters' hit points (enemies with more hit points are harder to eliminate). A Halton sequence (Halton, Smith, 1964) was used to select values evenly from a range of 20 to 400 hit points. This range was determined through a previous study (Vangsness, 2019). Selected values were randomized for each participant using the Fisher-Yates reshuffling algorithm (Black, 2005). Each participant had a different set of random difficulties, but those difficulties were presented in the same order for each cue-block.

2.2.2. Accessibility cue manipulation

Players' experience with accessibility cues was determined by two manipulations. Firstly, half of the hearing players and all the HOH players were required to complete the videogame with headphones but without any sound (the no audio condition) to simulate the most extreme experiences of Deaf/HOH players. Secondly, the presence of visual and haptic cues was manipulated within-subjects by changing the type of directional cues provided to participants every five levels. Presentation order was counterbalanced using a William's Latin Square design (Fisher, 1992). Together, these manipulations produced 8 conditions in a fractional factorial design (Fisher, 1992; see Table 1). On-screen instructions described the cues to players each time they changed.

2.2.3. Tutorial level

After listening to and reading game instructions, participants completed an eight-minute tutorial at the lowest difficulty setting. During the tutorial, participants gained two minutes of practice with each within-subject cue condition. These cue conditions were presented in the same counterbalanced order as was used in the primary levels.

2.2.4. Post-task survey

After the experimental task was completed, the participants completed a demographic questionnaire and an opinion survey about their experiences with the different cues. In this opinion survey, participants rated the perceived efficacy of each accessibility cue condition on a scale from 1 (not at all effective) to 5 (extremely effective). Copies of these surveys are available on the project's Open Science Framework page (https://osf.io/axub6/).

3. Results

A multi-level censored gamma regression was conducted using the brms package in R (Bürkner, 2019). Posterior distributions were estimated by drawing 20,000 samples over four chains. The first 10,000 samples served as the burn-in period and were discarded. Parameters were estimated using uninformed priors. The model's fixed effect structure included the main effects of participants' between-subject audio condition, within-subject cue condition, and within-subject workload (i.e., enemy HP). The fixed effect structure also included all two- and three-way interaction terms, as well as hours of videogames played per week to control for player experience. The random effect structure allowed the model intercept to vary by participant to control for unmeasured individual differences that might affect players' average performance. All variables were effect-coded and means-centred to reduce multicollinearity within the model and to allow the intercept to represent participants' average video game performance. Complete output from the model is available on the project's OSF page.

3.1. Hypothesis tests

3.1.1. Audio cues improved performance

A planned comparison indicated that on average, players who received an auditory cue performed better than those who did not (Bdiff = 1.33, 95% credible interval = 0.42, 2.23]). Similarly, participants without audio cues were more strongly affected by changes in difficulty (Bdiff = 0.73, 95% credible interval = 0.35, 1.11]). This suggests that audio cues helped participants play the game better, and allowed them to better respond to changes in game difficulty.

3.1.2. Accessibility cues helped those without audio

Planned comparisons also indicated that players without audio were assisted by accessibility cues. Haptic cues reduced the amount of damage players took by an average of 32 points/second (Bdiff = -1.44, 95% credible interval = -1.10, -1.77]) and visual cues reduced the amount of damage players took by an average of 27 points/second (Bdiff = -1.03, 95% credible interval = -1.03, -1.37]). Visual and haptic cues together reduced the amount of damage players took about as much as visual cues did alone (an average of 25 points/second, Bdiff = -0.91, 95% credible interval = -1.24, -0.57; see right panel of Figure 6).

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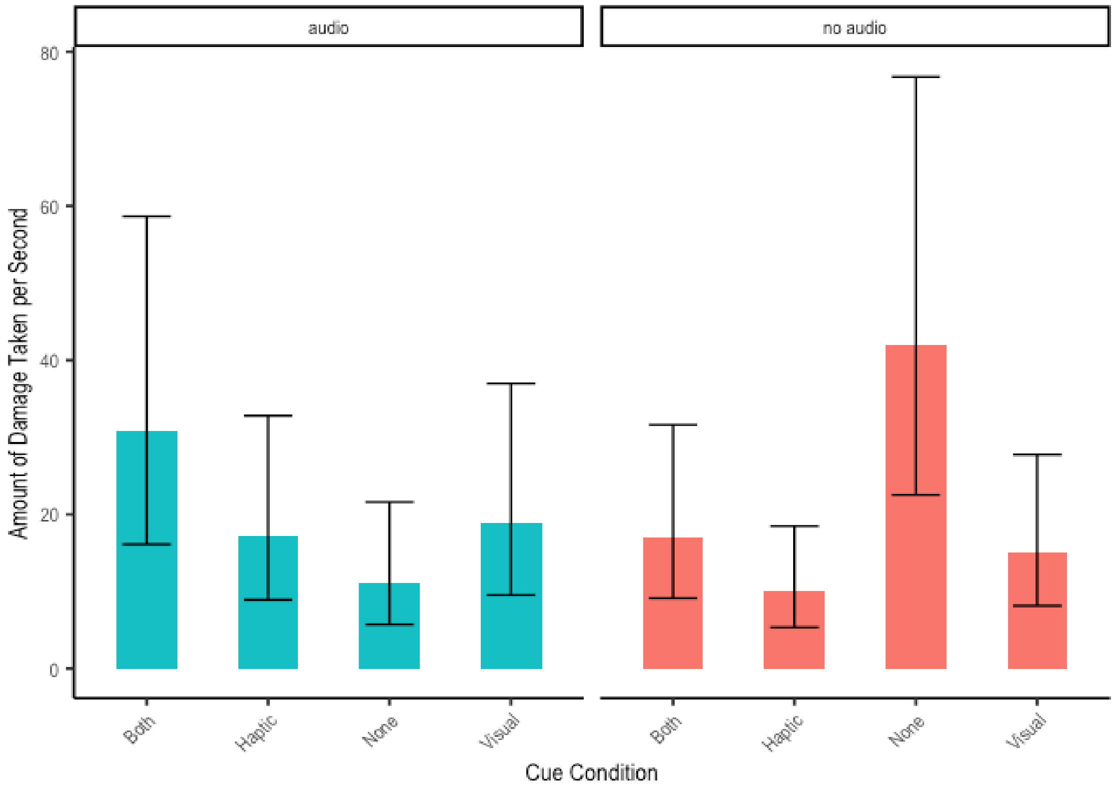
Figure 6. Accessibility cues' impact on performance depends on whether players have access to audio cues. Error bars represent 95% credible intervals.



3.1.3. Accessibility cues did not benefit those with audio

A different pattern was found among players who used the game's audio. These participants performed best when there were no additional cues. Adding haptic or visual cues did not substantially affect the amount of damage players took; however, adding haptic and visual cues together strongly impaired participants' performance – the amount of damage players took was increased by around 20 points/second under these circumstances (Bdiff = 1.02, 95% credible interval = 0.54, 1.51]; see left panel of Figure 6).

3.2. Exploratory analysis

3.2.1. Participants' perceptions did not align with reality

A multi-level linear regression was used to determine whether participants' beliefs about cue efficacy aligned with their performance in the game. The model included the main effects of log-transformed average rate of damage taken under each cue condition (performance), cue condition, and audio condition, as well as their higher-order interactions. Average rate of damage was log-transformed to accommodate the non-linear relationship between the average amount of damage players took and cue preference (additional detail are provided in the supplemental materials). The random effect structure allowed the intercept to vary across participants to control for other individual differences that affect judgment. These variables were regressed against perceived efficacy.

Players rated accessibility cues as equally effective, regardless of whether they received audio or not. Haptic cues were an exception, with participants in the audio condition rating them as much

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more effective than participants in the no audio condition (Bdiff = 2.46, SE = 0.32, t = -7.72, p < .001; see Figure 7).

Figure 7. Players' cue efficacy ratings did not align with their actual performance. Error bars represent 95% credible intervals.

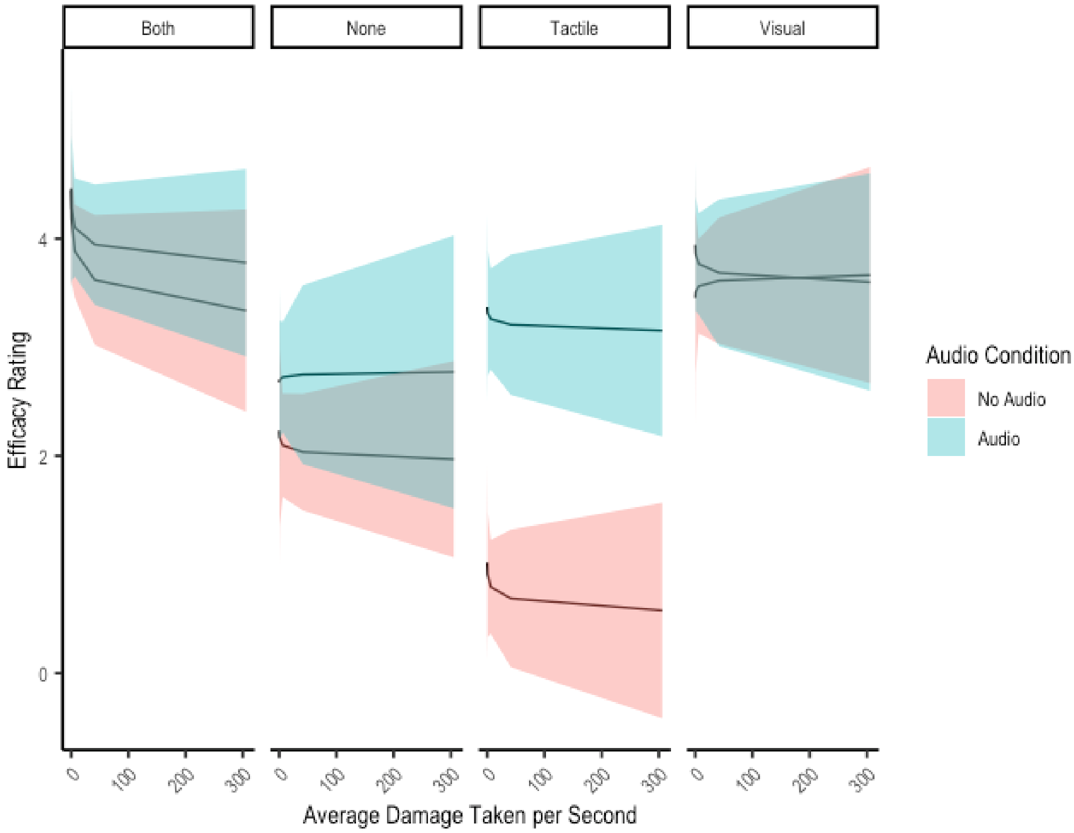

Table 3. Themes from the Thematic Analysis.

Cue	Theme	Count
Haptic	provided information that enemies were entering area	9
	difficulty distinguishing the right from the left cues	9
	provided directional information of the enemy's location	4
	did not provide enough information to be useful	4
Audio	provided information that enemies were entering area	7
	provided directional information of the enemy's location	4
Visual	provided directional information of the enemy's location	17
	binary nature of cue made it less helpful	9
None	did not provide enough information to be useful	13
Combined Cues	cues made up for what the other lack	2

3.3. Thematic analysis

A thematic analysis was conducted on responses to the free-response question about why participants preferred their selected cue condition. The thematic analysis identified four themes for haptic cues, two themes for audio cues, two themes for visual cues, one theme for no cues, and one theme for combined cues (See Table 3). Participants reported that haptic and audio cues provided information about when an enemy was entering the area, but fewer participants said these cues gave them directional information about the enemy character's location. It was strongly reported that visual cues provided the most directional information about the enemy character's location. Many participants reported that the no cue condition did not provide enough directional information. A few participants reported that having the cues together allowed the cues to make up for each other where one may lack.

3.4. Discussion

The results revealed that additional cues helped players without audio and provided no performance benefits to those with audio, supporting H1A. The results also indicated that players held strong beliefs about cue efficacy that did not align with the reality. Together, these results provide empirical support for players' anecdotal beliefs about cues while also illustrating that these beliefs are not grounded in reality. Accessibility cues do not provide an unfair advantage to hearing players; they fairly help those who cannot use a game's audio.

This study was a first step in looking at accessibility cues in the context of a video game; therefore, the video game was very simple. Accessibility cues provided only minimal information (i.e., left/right) about approaching enemies and were not essential to gameplay—players could see oncoming enemies without needing to attend to the accessibility cues. Nevertheless, our performance data indicated that players were clearly affected by the presence of accessibility cues. Still, efforts must be made to determine the generalizability of these results to more complex accessibility cues, as well as to other types of video games (e.g., puzzle games, first-person shooters). Additionally, this study included only a small sample of HOH players. Although HOH players' data aligned with that of hearing participants in the no-audio condition, future studies should seek to replicate these results with a larger sample of Deaf/HOH players.

The results of this study are consequential for the future progress of accessibility in games and make valuable theoretical contributions to the field by supporting the predictions of Multiple Resource Theory. Although players believe that redundant cues can provide an unfair advantage to hearing players by "dumbing down" a game, the results of this study clearly illustrate that this is not the case. Therefore, the best route for video game developers to take is to provide accessibility options for the players because not including these options limits the potential audience for their video games.

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