

LEVEL-UP! IDENTIFYING WAYS TO MAKE VIDEO GAMES MORE ACCESSIBLE  
FOR DEAF AND HARD-OF-HEARING INDIVIDUALS

A Dissertation by

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## LEVEL-UP! IDENTIFYING WAYS TO MAKE VIDEO GAMES MORE ACCESSIBLE FOR DEAF AND HARD-OF-HEARING INDIVIDUALS

The following faculty members have examined the final copy of this dissertation for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Doctor of Philosophy with a major in Psychology.

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## DEDICATION

### To my Parents –

You both have always made me believe that I was the smartest person in the world, even though that is not true, I am very proud of where I am today. You both have always been there to support me from my little league soccer games to each of my degrees. As a first-generation college student, it was a tough journey, but I will always remember where I came from and make sure to give back whenever I can. I love you both.

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### To my Cohort –

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### To my wonderful partner, Daniel –

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*“If I have seen further, it is by standing on the shoulders of giants.”*

– Isaac Newton

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## ABSTRACT

This study examines the impact of using tactile, directional cues in a 3D, third-person shooter video game. Depending on the condition, the game used audio, visual, and haptic cues to provide information about when and where enemy characters appeared. Participants without hearing loss played the video game under all three cue conditions (visual, haptic, both) and in one of two audio conditions (audio, no audio). Hard-of-Hearing (HOH) participants played the video game under all three cue conditions but were only assigned to the no audio condition. Data were collected on participants' performance, cue preference, and self-reported cue efficacy ratings. There were no differences in participants' performance across the cue conditions and higher workload decreased participants' performance. Adding visual cues acted as a redundant display and neither improved nor impaired participant performance. Participants' efficacy ratings did not always align with their performance. Qualitative data indicated that hearing participants' preferred cue condition included the visual and haptic combined condition. Their least favorite condition was the no cue condition. In contrast, HOH participants' favorite cue condition was the no cue condition. HOH participants' performance was similar to those of hearing participants' performance. This research is the first step in examining directional cues as accessibility features in the context of a video game. The results can be applied to other fields that utilize 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.

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## CHAPTER 1

### INTRODUCTION

Imagine going to the movie theater to see a highly anticipated film. All your friends have watched and enjoyed the movie; you've been looking forward to this all week. Suddenly, just before the movie starts, a worker informs you that the sound is not working and that there will be no captions provided. How are you supposed to watch and understand the movie? You have used sound to listen to movies your entire life. You could try to lip-read but are not well-practiced. You could even pull up a script of the movie on your phone and read it while the movie played. This would give you more information, but you would miss visuals happening on the screen. In general, most people would have a hard time following along with the plot and would not have the intended experience of the movie. People probably would not pay for this kind of experience. Yet, similar experiences happen to a number of Deaf and Hard-of-Hearing (HOH) individuals every day.

Hearing loss is more common than you think. The World Health Organization (2020) states that 466 million people around the world have lost greater than 40 decibels of sensitivity in their better hearing ear (i.e., have difficulty understanding speech). This hearing loss can range from the mild/moderate loss experienced by the Hard-of-Hearing (HOH) to the severe or complete hearing loss experienced by the Deaf. In the United States, there are 37.5 million Deaf/HOH individuals (National Institute on Deafness and Other Common Disorders, 2016). Additionally, in the United Kingdom, there are 11 million Deaf/HOH individuals (United Kingdom Government, 2017). Although significant hearing loss is present among one-third of individuals 65 and older

worldwide (World Health Organization, 2020), hearing loss can happen to anyone, regardless of age.

Deaf/HOH individuals want to go about their lives in a way that is similar to everyone else. This can be difficult without products that 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). When well-integrated, universal designs benefit all, the designs become “normal” and inconspicuous (Story, 2001). For example, building ramps were designed so people in wheelchairs could access buildings without assistance. Ramps not only help people in wheelchairs, but add convenience for parents with strollers, individuals with temporary injuries (e.g., crutches) and walkers, and toddlers who have trouble climbing stairs on their own. Ramps were not always a standard in building design but are now mandated under the Americans with Disabilities Act (Americans With Disabilities Act, 1990; Department of Justice, 2010). A similar evolution is happening in digital media where accessibility considerations are now required (Federal Communications Commission [FCC], 2010).

Despite the accessibility mandates happening in other areas, accessibility features in video games are still underdeveloped. The 21st Century Communications and Video Accessibility Act (CVAA) of 2010 was updated to account for modern communications (i.e., voice, text, and video chat; FCC, 2010). The CVAA now requires the video game industry to make any communication functionality (e.g., text, voice chat) and user interface (UI) accessible (Fogel, 2019). While these changes have improved the accessibility of communication in video games, the same requirements are not

mandated for other accessibility features in video games. Potential video game players have no idea what accessibility features are available before they purchase a game because it is not required to include that information on the advertising or packaging. Instead, the information on accessibility features is spread through the community by independent writers that review video games for accessibility features (e.g., <https://caniplaythat.com>). More recently, some gaming companies have started to share details about the accessibility features that are included in their games before they are released. For example, Ubisoft tweeted a list of all the accessibility features (e.g., controller remapping, subtitles, colorblind mode, etc.) included in Ghost Recon Breakpoint before the game was released (Ubisoft, 2019).

While Deaf/HOH gamers express concerns with accessibility features in video games, there has been some resistance to change because of genuine concerns that accessibility features would lessen the difficulty of video games and reduce players' enjoyment. However, accessibility features do not fundamentally change or "dumb down" a game; they provide greater access and make the game more enjoyable for everyone (Powers, 2015). For example, a parent may turn down the volume in a video game so as not to wake their baby. Similarly, a teenager that does not have headphones may want to mute a video game so as not to disturb other bus passengers. In these situations, accessibility features like subtitles and visual cues allow individuals to play games enjoyably, whether or not they can hear the sound.

Currently, there are 214 million gamers in the U.S. alone (Entertainment Software Association, 2020). Video game companies risk leaving behind nearly one in four Americans by not considering Deaf and HOH individuals in the design process.

There is enormous potential for increasing market share by improving the accessibility of video games. For example, accessibility options will enable a greater number of older adults to play video games when traditionally, there have been far fewer older adults who play video games as compared to the younger population. In 2016, 40.2 million older adults played video games at least once a month, and this rose to 50.6 million in 2019 (Nelson-Kakulla, 2019). Additionally, video games are a major source of enjoyment for many people (Beeston, 2018). This may be even more true for individuals who have a physical, mental, or developmental disability. According to a survey conducted in 2008, 94% of casual gamers that have a disability state that playing video games provided them with physical and mental benefits (Marketing Charts, 2008). Accessibility options not only improve the user experience, but they also provide the opportunity for more people to play.

Understanding how accessibility features improve the video game experience will reduce the stigma associated with accessibility features and make developers more willing to include them in their video games. It will also, in turn, improve other applications of video games such as research on human perception (Calvillo-Gómez et. al., 2011) and the methods used for training in the medical (Lynch 2010), aerospace (Loftin, 1994), and education (Egenfeldt-Nielsen, 2006) fields. Improving the accessibility of video games will not only be valuable to video game industries, but for all the avenues to which video games contribute.

This dissertation tested the efficacy of accessibility cues that can be used by hearing and Deaf/HOH players during gameplay. This was accomplished by inviting participants to play a video game that uses audio (administered through headphones),



haptic (administered through a controller), and visual (administered through on-screen arrows) cues. Players' performance in these cue conditions was compared to their performance in one of two conditions: haptic and visual cues together or no cues at all. The cues were presented under different levels of gameplay difficulty to determine whether cues reduce (i.e., make the video game "easier") or increase workload in a variety of circumstances. The main study manipulated cues between (audio vs. no audio) and within (haptic, visual, both) subjects. Difficulty was also manipulated within-subjects, and player's performance and cue preferences were collected continuously and at the end of the game, respectively.

## CHAPTER 2

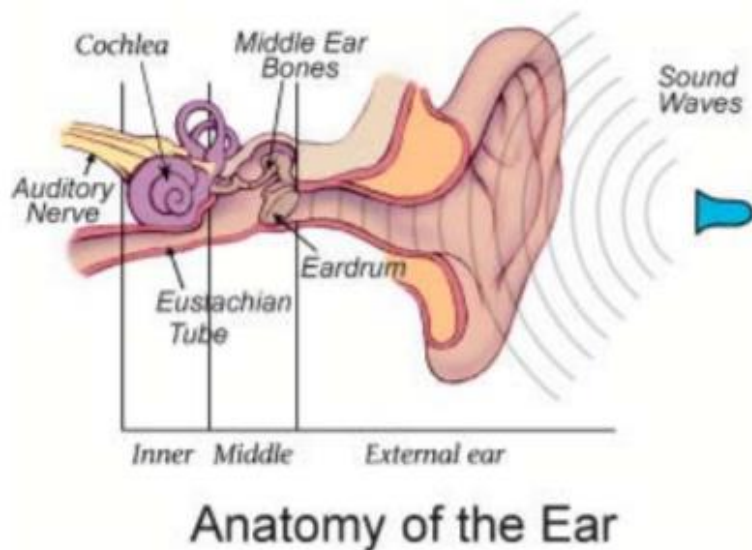
### LITERATURE REVIEW

#### The Processes of Hearing and Hearing Loss

Hearing happens through a series of steps. First, the pinna funnels sound (i.e., pressure) waves into the ear canal, where the sound causes the eardrum to vibrate against the first middle ear bone, the hammer. This vibration moves from the hammer to the anvil and lastly to the stirrup, which pushes against and transfers vibrations to the oval window. The movement of the oval window creates a movement of fluids within the inner ear. Here, hair cells on the cochlea move in response to the frequency of sound. Their movement transforms the sound waves into neural signals that pass through the auditory nerve to the brain (See **Figure 1**; Oghalai, 1997).

**Figure 1**

*The Anatomy of the Ear (Oghalai, 1997)*



**The Spectrum of Hearing Loss.** Hearing loss is diverse and exists along a spectrum. On one end of the spectrum are the Deaf, who have little or no functional hearing, and on the other end are people who have fully functional hearing. In the middle of the spectrum are Hard-of-Hearing individuals, people who have mild-to-moderate hearing loss or do not consider themselves part of the Deaf community. The Deaf community distinguishes itself from people who lose their hearing from illness, trauma, or age because these individuals do not share the Deaf culture's knowledge, beliefs, and practices (National Association of the Deaf, 2020).

There are two main types of hearing loss. Sensorineural hearing loss occurs when there is damage to the hair cells of the inner ear or the auditory nerve. This form of permanent hearing loss prevents or weakens hair cells' ability to detect fluid movement in the cochlea. Because information on the loudness and clarity of sounds is lost, devices like hearing aids or cochlear implants usually help with sensorineural hearing loss. In contrast, conductive hearing loss occurs when damage to or blockage of the outer or middle ear prevents sound from transferring to the inner ear. This can be a permanent or temporary condition that reduces the loudness of sounds. An example of a temporary condition is an obstruction blocking the ear canal; the obstruction can simply be removed. Otherwise, turning up the volume on devices or using a hearing aid or bone-anchored implantable device can help increase the loudness of sounds (Mroz, 2020). When a person presents with a combination of sensorineural and conductive hearing loss, it is referred to as mixed hearing loss.

## **The Importance of Alternative Cues**

Information can be conveyed in many ways. For example, information can be conveyed using visual, auditory, and haptic cues that convey warnings, notifications, and/or feedback while a person uses a device or performs a task. A problem arises when only one type of cue is used to convey important information. For example, imagine an ambulance that used only a siren to notify drivers of its presence. Both Deaf drivers and hearing drivers with their radios turned up would not be able to hear the ambulance. Another common example are fire alarms, which give loud warnings that Deaf individuals most likely cannot hear. Deaf individuals would need to be near the fire alarm and see the flashing lights to act. In a similar way, video games use cues to communicate information to their players. Problems arise when only one type of cue is used.

**Cue Use in Video Games.** Video games can be difficult for people with hearing loss 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. Visual and haptic cues can also be used in this manner, such as an on-screen bar to provide information about a character's health, or a rumble to indicate when a player is taking on damage. Auditory, visual, and haptic cues can also be used to convey aesthetics (e.g., background music, character art, and a rumble during a cutscene).

When auditory cues are the only means by which a game conveys important information, it can significantly impact peoples' playing experience. For example, hearing individuals who have issues confirming their actions (e.g., clicking sound), have

increased reaction times, experience decreased presence within the game world, and miss important information conveyed by auditory cues when their sound is unexpectedly turned off (Jørgensen, 2008). Although game developers may not purposefully disadvantage players in this way, games can be made more accessible with little to no cost and labor if developers plan the accessibility features from the start of the game instead of as an afterthought (Powers, 2015).

Sound within video games can range from the aesthetic to the informative. For example, background music (an aesthetic cue) is often used to convey emotion or provide entertainment. Music can also be used to signal changes in the game. For example, a specific song may indicate that an important character is nearby. The player can integrate this information with other cues and make an informed decision on the next steps they will take in the game. In many game genres, gaining information about the current situation is vital. For example, players in a fight need to know information about the health and abilities of their character, their teammates' characters, and their enemies. If they do not get this information quickly, their character can die, and they must wait before they can meet back up with their team. Often games will provide this information through one modality (e.g., audio only) and this is referred to as a single-cue display.

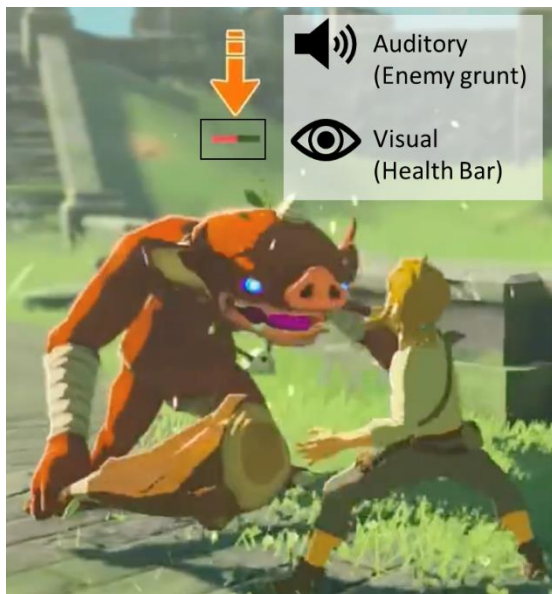
**Single-Cue Displays.** Single-cue displays use only one modality (e.g., auditory) to provide information to the player. An example would be a game that notifies the player that they picked up an item with only a sound. Single-cue displays are beneficial in that they provide key information to the user; however, when single cues are inaccessible, some people do not receive this information (e.g., the Deaf/HOH, users

with a muted device). Single-cue displays are detrimental in that they fail to give the user alternative methods by which to obtain information. In contrast, multi-cue displays provide the same information using several senses.

**Multi-Cue Displays.** When multiple senses (i.e., visual, auditory, haptic) are involved in an interface, the interface is referred to as a multi-cue, multi-sensory, or multi-modal display (Ng & Nesbitt, 2013). There are three types of multi-cue display mappings: complementary, redundant, and conflicting displays (Ng & Nesbitt, 2013; Pao & Lawrence, 1998). Multi-cue displays are meant to enhance the user's performance and make the display more accessible by providing the cues in multiple ways (Lu, 2011); however, this is not always the case (Ng & Nesbitt, 2013).

**Figure 2**

*A Complimentary Display*

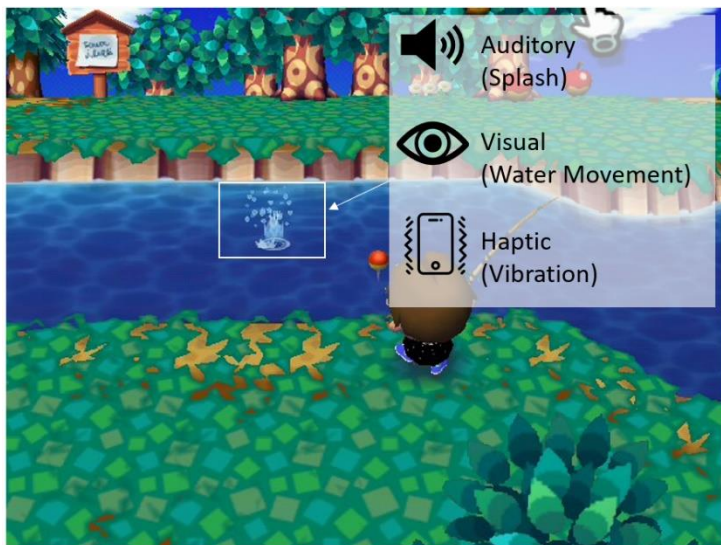


*Note.* The health bar and grunting sound indicate that the player has struck the enemy (icons added to original screenshot from The Legend of Zelda: Breath of the Wild).

Complementary displays provide the same information to different sensory channels with varying levels of detail (Ng & Nesbitt, 2013). For example, when a player damages an enemy character, the enemy character may make a grunting sound. At the same time, the enemy's health bar may visually decrease (see **Figure 2**). The sound lets the player know that the enemy was hit, but the health bar provides more exact information: the amount of damage that was dealt to the enemy and the amount of health the enemy has left. These types of displays typically result in better performance because they involve different modalities (e.g., auditory & visual) which pull from different resource pools (Wickens, 2002).

**Figure 3**

*An Example of a Redundant Display*



*Note.* An auditory splash, a visual splash, and a haptic pulse all indicate that the fish has bitten the line (icons added to original screenshot from Animal Crossing)

Redundant displays present the same information to multiple senses. Redundant displays can increase the user's confidence and decrease their perceived workload but may not increase the user's performance as compared to single-sensory displays (Ng & Nesbitt, 2013). For example, when a fish bites the line in a fishing game, a visual splash in the water, a splash sound, and a haptic controller vibration all tell the player that the fish bit the line; this information is given to three different senses (see **Figure 3**).

Conflicting displays are those that use one or more modalities to provide the user with contradictory information, thereby decreasing performance and increasing confusion (Ng & Nesbitt, 2013). Imagine you are playing a video game that contains mimics, enemies that can disguise themselves as inanimate objects. These mimics visually appear as a non-threatening object (e.g., a lamp) but may make unique sounds that alert you to their actual identity. In this example, a visual and auditory cue conflict with one another and may leave people confused on how to best proceed (Ng & Nesbitt, 2013). In this case, the conflict is intentionally designed to increase the difficulty and enjoyment of the game; however, that is not always the case. Conflicting displays can also decrease performance when they feature valid cues that are cross-mapped to different outcomes. For example, Animal Crossing (see **Figure 3**) is programmed to produce a haptic pulse when a fish nibbles the line that a player is using to fish. However, this vibration happens with the same intensity as when the fish bites the hook. Players are unable to use these two haptic cues to determine whether to wait for a bite or pull the fishing line, so they can become confused, and their performance may decrease.



## **Haptic Cues**

Research on haptic cues demonstrates that haptic cues can precisely convey directional information (Butter et al, 1989; Ho et al., 2005; Rupert, 2000; Tan et al., 2003). Tan et al. (2003) used haptic cues to convey directions to participants. They found that participants were able to identify the correct direction on 81% of the haptic cues they received. Haptic cues are able to capture attention (Gilliland & Schlegel, 1994; Sklar & Sarter, 1999; Tan et al., 2003). In a separate task, Tan et al. (2003) used haptic cues to prime participants to an on-screen location. They found that participants were able to respond more quickly to valid haptic cues as compared to invalid haptic cues. In other words, participants used haptic cues in the same way they might have used visual cues. Additionally, participants respond more rapidly to valid haptic cues, as compared to valid visual cues (Butter et al., 1989) and invalid haptic cues (Ho et al., 2005).

Haptic cues presented alone or in combination with visual cues result in faster reaction times (Ho et al., 2005; Li et al., 2012; Sklar & Sarter, 1999; Van Erp & Van Veen, 2001) and are less disruptive to task performance (Hameed et al., 2009; Hopp et al., 2005), as compared to visual cues alone. Haptic cues also improve performance in highly visual settings, such as driving. For example, Van Erp and Van Veen (2001) asked drivers to follow navigation instructions given via visual arrows (presented on a display), haptic vibrations (presented on a seat), or both cues together. Drivers who received haptic cues alone or alongside visual cues had quicker reaction times as compared to participants who only received a visual cue. Drivers also reported that haptic cues – both by themselves and when paired with visual cues – did not increase

their workload as much as visual cues did alone. Case studies indicate that haptic cues are even beneficial when used in highly vibratory environments (e.g., helicopters and boats; Van Erp et al., 2004).

## **Accessibility in Video Games**

Accessibility's goal, in many cases, is to provide access to more people without creating unnecessary workload for the players that need it. A little challenge in video games is what makes them fun, but the non-accessible features of a game prevent some players from participating. Accessibility options allow more people to experience the video game. Highlighted below are the most common accessibility features in video games. Although there are other important accessibility features relating to mobility or cognitive accessibility (Ellis et al., 2020; Microsoft, 2020), they are not within the scope of this project.

**Visual Accessibility.** Visual accessibility receives the most attention, both in research and in terms of the accessibility features included in video games. One of the most common accessibility options assigns alternate cues to colors. This accessibility feature allows color-limited individuals to play the game (Barlet & Spohn, 2012; Ellis et al., 2020). For example, the game Hue has an option to add symbols that correlate with each color (see **Figure 4**). Any increases in workload due to the added symbols are minuscule and furthermore, the symbols are optional for the player to include. Another example of this concept is a stoplight, which uses both color and the location of the lights to signal direction. Other, less-common examples of visual accessibility include the use of a dyslexia-friendly font, a readable font size, and providing enough contrast between text and the background (Barlet & Spohn, 2012; Ellis et al., 2020).

## Figure 4

### *An Example of a Visual Accessibility Feature*



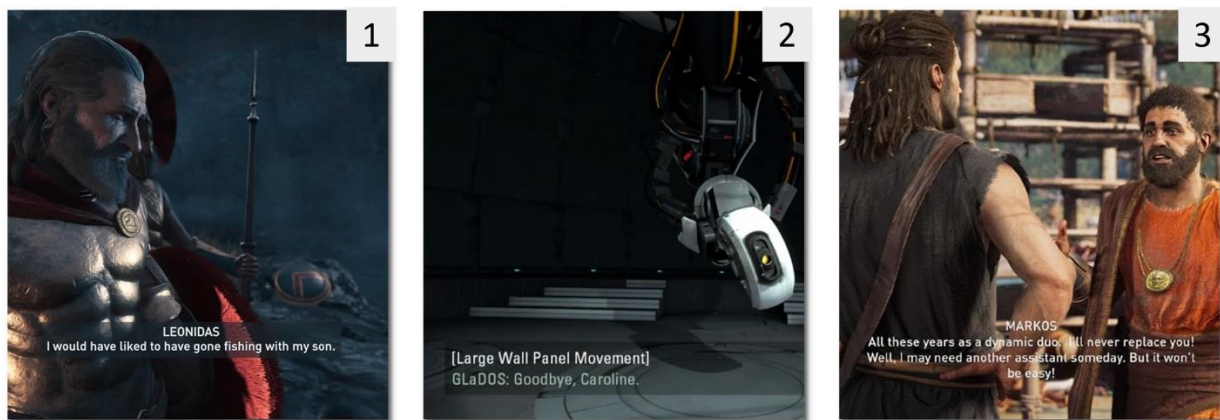
*Note.* The left image shows the game Hue without the symbols accessibility feature.

The right image shows the game Hue with the symbols accessibility feature.

**Auditory Accessibility.** The most common auditory accessibility features are subtitles/closed captions; however, not all subtitles/closed captions are made equal. Subtitles consist of written character dialogue; whereas closed captions include descriptions of audio cues (see **Figure 5**). Closed captions are preferred because they provide additional detail. Ideal captions should use a readable font, have an adjustable size, have a transparent color background, list the name of the speaker, and be presented at an appropriate number of words per minute (Barlet & Spohn, 2012; Ellis et al., 2020).

## Figure 5

### *Examples of Subtitles and Closed Captions*



*Note.* Image 1 shows subtitles with a transparent background; Image 2 shows closed captions and subtitles with a transparent background; Image 3 shows subtitles without a transparent background. (Image 1 & 3 are from Assassin's Creed: Odyssey; Image 2 is from Portal 2)

Games should ensure essential information is not conveyed by sound only (Barlet & Spohn, 2012; Ellis et al., 2020). For example, an alarm sound without a corresponding visual cue creates a barrier in that the sound will only be noticed by hearing players who keep the volume turned on. Ideally, video games should provide players with options to adjust the background noise, speech, and music separately to prevent any information from being masked by other sounds (see **Figure 6**; Barlet & Spohn, 2012; Ellis et al., 2020). Because the spectrum of hearing loss is so vast (and players' needs diverse), giving players the ability to adjust different volume settings to their needs is an effective accessibility option.

**Figure 6**

*Volume Adjustments for Different Sounds*



*Note.* Diablo 3 has slider adjustments for different sounds (master volume, effects volume, music volume, voice volume, ambient volume, and sound channels).

## **Multiple Resource Theory**

Information-rich environments, like video games, can be overwhelming to people, especially if the task must be performed well. The abundance of cues in information-rich environments leads people to struggle to pay attention to relevant information (Rosenholtz et. al., 2007). For example, in a competitive team game like Overwatch (<https://playoverwatch.com/en-us>), players must pay attention to not only the features of the game (the current map layout, the timer), but also to their own character's status (health, ability percentage recharged, positioning), the status of their teammates, and the status of enemy players. There are many different places the player can allocate their attention, so they must decide where to focus their attention at any given time.

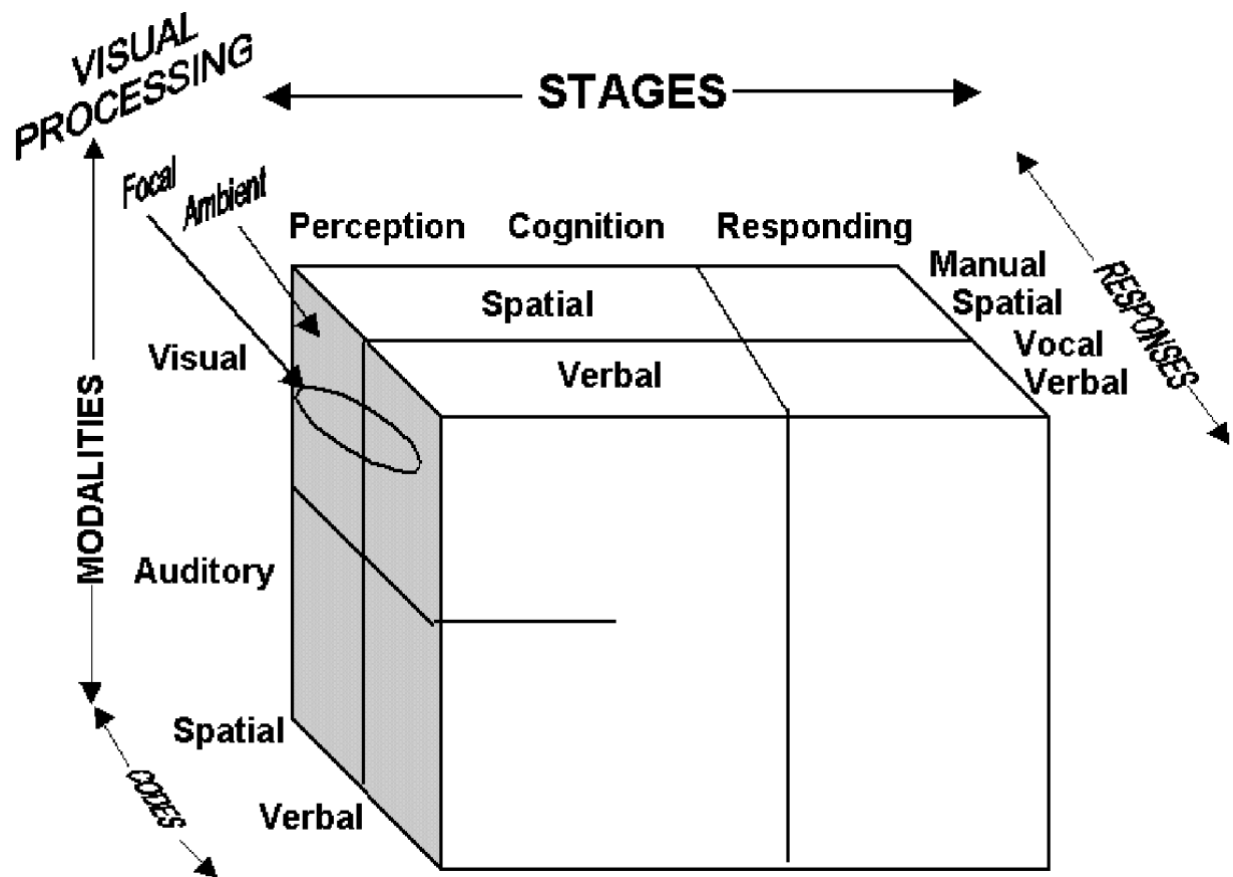
A key theory in understanding how people allocate their attention is Wickens' (1991) multiple-resource theory (MRT). MRT predicts that performance is affected by a

person's resource allocation. Resource allocation depends on an attended stimulus' stage of processing, modality, processing code, and response channel, relative to other stimuli to which attention may be directed (see **Figure 7**).

The stages of processing, depicted across the top of the MRT model (see **Figure 7**), are experienced in order and function as a bottleneck, where all information is theoretically perceived, but only some information is important enough to move through each stage (Broadbent, 1958). In the earliest stage of processing, only some of the cues that a person attends to are processed. Then, a person must decide whether it is necessary to act upon that information. Video games have many cues, and players must decide which ones are worth responding to. In order to play a video game, a person must first attend to and perceive the visual, auditory, and haptic elements of the game. New players must take a bottom-up approach and are drawn in by the characteristics of the stimuli (e.g., motion; Navalpakkam & Itti, 2006). Once a player becomes more familiar with the game, they will utilize a top-down strategy and constrain their attention to areas of importance that are identified based on previous knowledge (Navalpakkam & Itti, 2006; Soto et al., 2006). Once the selected cues have been perceived and processed, a person can integrate them with their current understanding of the game (i.e., cognition). Together, a person's perception and cognition inform their actions in the game (i.e., responding).

**Figure 7**

*The Four-Dimensional Structure of Wickens' (2002) Multiple Resource Theory Model*



Someone playing a video game might perceive, process, and/or respond to different cues that provide visual (e.g., graphics, text) or auditory information (e.g., music, alerts, sound effects). People are better able to divide their attention between visual and auditory information (cross-modal) than they are able to attend to two visual stimuli or two auditory stimuli simultaneously (intra-modal; Wickens, 2002). Intra-modal information is more likely to result in interference; if a video game relied entirely on auditory cues, one cue might mask another. Similarly, too many visual cues can overwhelm the visual channel and make it difficult to play a video game. Cross-modal

cues are easier to distinguish, and research has shown advantages in participants' accuracy and completion time when tasks utilize cross-modal cues (Wickens, 1980).

Third, the visual channels shown within the visual modality on the left side of the MRT model (see **Figure 7**), present the distinction between focal (e.g., used when reading a book) and ambient vision (e.g., used when lane keeping on a highway; Wickens, 2008). Focal vision is required for fine detail and recognizing patterns, like aiming in a video game. Ambient vision is mostly peripheral vision and sensing orientation (Wickens, 2002), like seeing an enemy move on the corner of your screen. Focal and ambient vision use different resources (Wickens, 2002) and are both important in a video game. Imagine you are playing a racing game. Focal vision is needed for the player to focus on the track ahead of them and any obstacles that may appear. Ambient vision is necessary for noticing if another player is getting close to passing you. If a video game needs to notify the player of something critical, the visual cue should appear toward the center of the screen. It will be easier to see as compared to a cue that is on the edge of the screen.

Finally, the processing codes displayed across the bottom left of the MRT model (see **Figure 7**), show that spatial and verbal channels are consistent across all stages of processing (Wickens, 2002). When a task requires spatial channels, verbal responses do not influence performance, but spatial responses (e.g., manual typing) do (Wickens, 2002). Imagine you are playing a multiplayer video game and need to communicate with your teammates during a round. You are using a controller to move your character, so it would be more advantageous to communicate through voice chat (verbal) rather than having to type (spatial) into the chat box. The spatial aspect of



typing will interrupt gameplay much more than the verbal chat will. However, the reverse would be true if a game required verbal commands. Then, using voice chat (verbal) to communicate with teammates would interfere with gameplay more than typing (spatial) to teammates would.

**Haptic Modality in MRT.** Wickens' MRT model does not account for the haptic modality, however, Wickens et al. (2015) state that the haptic modality acts as an additional perceptual resource channel that is similar to the auditory channel. That is, auditory/visual tasks have similar timesharing (i.e., switching attention from one task to another concurrent task rapidly) as do haptic/visual tasks (Lu et al., 2011; Wickens et al., 2015). Haptic cues have many benefits that make them a viable option for interfaces: they are transient, high in spatial and temporal sensitivity, 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). Sklar and Sarter (1999) found that pilots with haptic-only and haptic-visual cues had faster reaction times than those who only received visual cues. This was especially true under conditions of high workload (Sklar & Sarter, 1999). This finding was further supported by a meta-analysis of 23 studies; however, the researchers note that more complex cues (complex: direction, simple: warning) and urgent cues (urgent: alarms, less urgent: notifications) were best presented as auditory cues (Lu et al., 2011). The authors warn that the nature and purpose of each cue is vital to consider before applying them to a display (Lu et al., 2011).

MRT explains why some tasks are efficient and can be completed concurrently (e.g., walking and talking; reading while listening to instrumental music) while others are

inefficient and compete for a person's limited attentional resources (e.g., talking while reading, problem solving while listening; Wickens, 1991). When tasks compete for available resources, people must decide which task to allocate more of their attention towards. The decision about how to allocate attention to is influenced by a task's workload, which task is "favored" or more important at the time, and the timesharing of the task (Kantowitz & Knight Jr, 1976; Wickens, 2002). These allocation factors can cause performance on the task designated as "secondary" to drop (Wickens, 2002). For example, a nurse attending to an auditory warning indicator (i.e., current primary task) will be more disrupted by a doctor's orders (i.e., critical secondary task) than by the forms they are completing on a computer screen (i.e., noncritical secondary task).

## **Workload**

Workload and MRT are closely related. MRT is sometimes referred to as a workload theory; however, MRT is unique because it makes specific predictions about performance under different workload conditions (Wickens, 2002). In high workload conditions, MRT predicts that performance will deteriorate, especially in "overload" situations where the participant has two or more intra-modal concurrent tasks and not enough time to do them (Wickens, 2002). Under low workload conditions during which the participant is engaged, performance will be high; but if the participant is not engaged, they can experience an "underload" situation (Stanton et al., 1997). In "underload" situations, performance drops (Stanton et al., 1997).

MRT also offers specific predictions about which kinds of accessibility cues should be used under specific circumstances. If a video game is highly visual and fast-paced (e.g., third-person/first-person shooter), additional visual cues may increase

workload and decrease the player's performance (Wickens, 1991; Wickens, 2002). In this case, auditory cues may be better because they make use of a different channel (Wickens, 2002). In contrast, if a video game uses the auditory or haptic modality to convey critical gameplay information (e.g., an RPG), then additional of visual cues may be more beneficial to the player than additional auditory/haptic cues. When designing for accessibility, video game developers need to consider both the needs of the player (e.g., Deaf/HOH) as well as the primary channel through which they communicate to the player.

Although added workload can be negative, an appropriate amount of challenge is an important part of keeping players engaged (Csikszentmihalyi, 1975; Deci & Ryan, 2000). Workload in an experimental setting can be manipulated by increasing or decreasing different aspects of a task (Vangsness & Young, 2017; Vangsness & Young, 2019; Vangsness & Young, 2020). For example, in a video game task, a researcher could increase the amount of damage the enemies can deal towards the player to increase the difficulty required to complete the task. Similarly, factors such as enemy damage could be decreased for the player to make the video game task easier.

### **Statement of Purpose and Contribution**

The current research is not only consequential for the future progress of accessibility in games, but it also has valuable theoretical contributions. As multiple resource theory (MRT) theorizes, using different modalities to convey information can result in better performance as compared to using a single modality to convey information. Based on MRT, utilizing additional (e.g., haptic or visual) cues will help performance. It is essential to understand how these cues might impact performance to

continue making games more accessible. Increasing the knowledge of possible ways to communicate critical information to users will not only help the video game industry but all the other areas that utilize video games and cues to communicate information.

## **Study Outline**

The purpose of this study was to test directional cues impact on performance and preference. An initial qualitative pilot study was conducted to understand what barriers were faced by the Deaf/HOH community in video games. The pilot study revealed that directional cues were a major barrier for the Deaf/HOH community. Therefore, the main study was designed to test how different accessibility cues affected player performance in a videogame task. Participants played a video game that utilized visual, haptic, and audio directional cues. Both hearing participants – and a small number of HOH participants – were recruited. Both qualitative and quantitative data were collected from this second sample.

## **Research Hypotheses**

**H<sub>1</sub>:** The addition of cues will increase participants' performance.

**H<sub>2</sub>:** Increased workload will decrease participants' performance, but this relationship will be attenuated by the presence of additional cues.

**H<sub>3A</sub>:** The addition of visual cues will act as a redundant display and neither improve nor impair performance.

**H<sub>3B</sub>:** The addition of visual cues will act as a conflicting display and impair performance.

In addition, this dissertation answered the following questions through exploratory analyses:

**Q<sub>1</sub>:** Are hearing and HOH participants' cue efficacy ratings reflective of their performance in the game?

**Q<sub>2</sub>:** Do hearing and HOH participants differ in their preference for cue types?

## CHAPTER 3

### PILOT DEVELOPMENT & PROCEDURE

Pilot interviews were conducted with members of the Deaf/HOH gaming community to ensure that follow-up research would positively impact the Deaf/HOH. The purpose of these pilot interviews was to identify the problems that people in the Deaf/HOH community faced as they played video games. One such issue was selected for further study in the dissertation.

#### Method

**Participant Recruitment.** Eight participants (two female, one non-binary) were recruited by email using convenience and snowball sampling methods. Six of the participants were Deaf and two were HOH. The participants reported playing a mixture of console (e.g., PlayStation, Xbox, Nintendo) and PC games. Additional demographic information about the participants is provided in **Table 1**.

**Table 1**

*Pilot Participant Demographic Information*

	<i>M</i>	Range
Age	29.80	22–44
Weekly Gameplay Hours	4.25	3–9

**Interview Strategy.** Semi-structured interviews were conducted in-person ( $n = 1$ ) and through Discord ( $n = 7$ ), a text chat app. Interviews were transcribed by copying and pasting text into an excel sheet from the Discord chat or the researcher notes. Questions were formulated to gather demographics and to inspire discussion on the topic of accessibility. Follow-up inquiries were made based on clarification needs or

researcher interest in specific topics discussed by the participant. A detailed list of all questions can be found in **Table 2**.

**Table 2**

*Interview Questions*

---

**Planned Questions**

1. How old are you?
2. Do you identify as a male, female, or other?
3. Are you Deaf or Hard-of-Hearing?
4. What systems do you play?
5. How often do you play video games?
6. What place do video games have in your life?
7. What types of games do you play?
8. How has being Deaf/Hard-of-Hearing affected your experience with games?  
Have you ever felt like you weren't able to experience a game in the intended way?
9. Have you encountered problems in games related to being Deaf/Hard-of-Hearing?
10. Do you use accessibility tools? What types?
11. Have you encountered any barriers while gaming which you weren't able to overcome with tools available to you?

**Follow-up Questions**

1. Do you use vibration or find it helpful at all?
  2. What do you think if you controller vibrated on the right or left to indicate critical information in that direction?
  3. What does Fortnite do that you like? & why do you play without vibration sometimes?
  4. Have you seen the mobile version of Fortnite? It was designed to be played without sound.
  5. Do you have any games that you think do a good job with accessibility or a really bad job that I should look at?
  6. Some games like Overwatch have features where you can state needs like I need healing or group up. Do you use these callouts?
  7. I was curious because you mention directional sound being a problem. Do you think directional vibration on a controller would be helpful?
  8. You mentioned using vibration. If you had directional vibration to inform you of critical information in the game, what do you think of that?
-

## Results and Discussion

An interpretative phenomenological analysis (IPA) was used to make sense of the data (Smith et. al., 1999; Smith & Shinebourne, 2012). IPA explores the participants' personal accounts and experiences through a dynamic process with an active role for the researcher. This process allows the researcher to get an "insider's perspective" of phenomena that they are unable to experience directly or completely (Conrad, 1987). This analysis was used to develop and report patterns of meaning in a thematic form (Larkin et. al., 2006). These themes highlighted three common problems and barriers that Deaf/HOH participants experienced.

**Team Communication.** Many gamers, including the Deaf/HOH community, play to maintain relationships with friends and family. They often do this through multi-player games, which involve working against other players in solo-play or working toward the same goal as teammates in team play. However, multi-player, team games require teamwork and communication; Deaf/HOH gamers voiced challenges and dissatisfaction with existing team communication features. One participant stated, "I avoid MMOs [Massive Multiplayer Online games] because those often rely on voice chat and that's hard for me."

One major reason for Deaf/HOH gamers' dissatisfaction with team communication was that not all games offered a text chat box. Voice chat is problematic for Deaf/HOH gamers because the audio quality of each player's microphone can be drastically different. If the quality of a teammate's microphone is bad, it can be hard to understand what they are saying and almost impossible for a Deaf/HOH individual. This



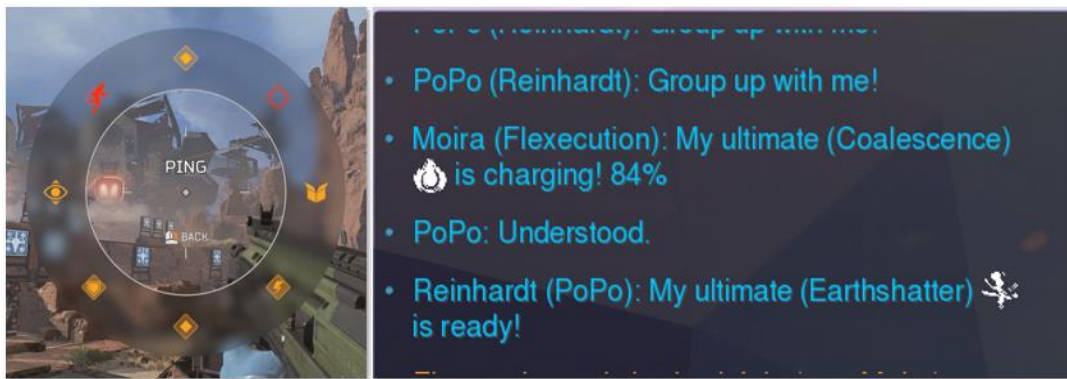
can make a big difference in games that require team strategy, where it is critical to inform your teammates of different events.

Some games offer specific tools to help with in-game communication methods, such as Apex Legend's ping system or Overwatch's callout system (see **Figure 8**).

Additionally, HOH gamers expressed an interest in detailed sound adjustment settings that allow the user to adjust the background music, in-game sound, and voice chat separately. This feature would allow players to isolate and focus on hearing only the vital sounds.

## Figure 8

### *Examples of Team Communication Systems*



*Note.* The first image displays the ping system in the game Apex: Legends. The second image shows the game Overwatch's chat box which displays in game callouts.

**Subtitles and Closed Captions.** Deaf/HOH gamers also indicated a preference for subtitles and closed captions, which provide critical information and allow gamers to be pulled into the storyline (see **Figure 5**, images 1 and 2 respectively). If a game does not have subtitles or closed captions, Deaf/HOH gamers are less able to play because they lack information that is critical for the player to progress. One participant recalled

an instance of this occurring, “I recently played the Hanged Man [game] and it didn’t have descriptive noises for the telephone [and] I was supposed to pick it up [to progress in the game].” Games without captions leave Deaf/HOH gamers frustrated and confused. Even games with closed captions or subtitles were sometimes considered bad by the Deaf/HOH gamers. Subtitles that do not have a transparent background are harder to read in comparison to subtitles that have them (see **Figure 5**, image 3, and images 1 & 2 respectively). Games that exclude “less important dialogue... like in-game conversations between NPCs [non-player characters]” are perceived as frustrating. Small text and fast scrolling speeds also gave gamers concern because it prevented them from reading the text. Allowing gamers to customize the subtitles to their own needs will eliminate these issues and improve the game’s experience for everyone, whether they are a member of the Deaf/HOH community or a hearing individual.

**Directional Feedback.** Finally, Deaf/HOH gamers faced challenges knowing when enemies were approaching or where bullets were coming from. This issue was prominent in first-person shooter games that involved other human players (as opposed to AI). Players are harder to compete against, so understanding their location relative to you is crucial to making an appropriately fast reaction. Not knowing what direction bullets or footsteps come from leads to impaired performance (e.g., lost points or lives). Several Deaf/HOH gamers indicated that this was a determining factor in why they gave up playing a particular game: “There are also games that I used to enjoy playing but

could never fully appreciate due to the strong focus on directional audio. In the end, I just gave up trying to play them.”

## Figure 9

### *Fortnite's Visual Sound Option*



*Note.* The orange arc shows the direction that the gunfire sound is coming from. The blue arc shows where the footsteps sounds are coming from.

While most games do not have directionality cues, a few are trying. Fortnite, for example, has a visual sound option (see **Figure 9**). This option provides a ring in the center of the screen that not only shows the direction of sound but also uses an icon to identify what that sound is (e.g., footsteps or gunfire).

**Workarounds.** In addition to identifying barriers to gameplay, participants shared several workarounds they used to improve their gameplay experiences.

As stated previously, team communication often relies heavily on voice chat. If other options (e.g., text-based chat) are not available to Deaf/HOH gamers, they must resort to other means. Some gamers mentioned having a strategy meeting with their team before their games. This would help the team have an idea of what each of them would plan to do during a match. However, this strategy was less helpful when sudden

changes occurred during gameplay. For example, things can change quickly if a team member dies. Sudden changes require teams to re-strategize mid-fight, and a Deaf/HOH player would not be able to communicate using voice chat in this situation.

When a game does not provide subtitles, Deaf/HOH gamers have tried emailing the companies for a transcript, which often ends in mixed success. Even when companies provide transcripts, the results can be negative: Not only must gamers wait for the company to send it to them, but they must also try to map the dialogue to the scenes happening on the screen. Additionally, very few games include closed captions but when they do, they are usually well received. The option to have sound appear as dialogue really helps in games where the sound is important to being successful at the game.

If a game does not provide an in-game tool (e.g., Fortnite's visual sound) to help with directional feedback, many gamers will resort to external devices for assistance. Some headphones provide haptic feedback, which can be used with or without sound to understand directionality. A few gamers also mentioned using a haptic vest (<https://subpac.com>) to feel sounds when playing shooters and other games where the sound is critical to the mood and experience (e.g., horror games). One participant stated, "[The Subpac] helps me a lot to locate sounds while playing Rainbow Six's Siege and horror games."

## **Discussion**

Barriers to Deaf/HOH players' gameplay experience are of increasing importance, as accessibility is becoming a selling point for many games. Players indicated challenges associated with team communication, subtitles/closed captions,

and directional feedback. These issues outline areas that require additional attention within video game design. Although some video games use alternative cues, such as directional sound (e.g., Fortnite's visual sound), there are reasons to believe these cues may hinder players and impair their performance. Some indication of this comes from the field of design: when cues are loaded onto the same MRT modality, they can be confusing (Wickens, 2002). MRT also offers specific predictions about which cues are best. Namely, MRT predicts that people who are playing visual-based games should receive auditory/haptic cues while those who are playing audio/haptic-based games should receive visual cues (Wickens, 2020). These kinds of design decisions are important because both task characteristics (e.g., enemy damage rates) and cue-driven workload (e.g., additional visual cues presented during a highly visual game) are a resource nightmare that will increase workload differentially for Deaf/HOH players (Wickens, 2020). This will cause video game developers to lose parts of their target audience and may even turn some hearing players off from games entirely.

These issues also outline areas for further research. This dissertation focused on the barrier of directional feedback because there was less work done in this area as compared to the areas of subtitles/closed captions. This research contributed a deeper knowledge of haptic cues' impact on user performance. The results help create games that are not only more accessible but more engaging as well. Breaking down the barriers to gameplay will ensure that more people have the opportunity to engage in video games. This knowledge not only helps Deaf/HOH gamers, hearing gamers, and blind gamers, but it adds to the pool of haptic cue knowledge for other fields that utilize cues (aviation, military, driving, etc.).

## CHAPTER 4

### METHOD

#### Participant Recruitment

**Hearing Sample.** 39 hearing participants (23 males, 16 females) were recruited through the SONA system, recruitment flyers, and word-of-mouth. SONA participants received course credit as compensation. Participant demographics information is displayed in **Table 3**. One participant's demographic data was removed because of researcher error in survey administration. Most of the participants considered themselves gamers (29) and had experience with video games on PC (29), gaming consoles (26), and mobile phones (20).

**Table 3**

*Hearing Participant Demographic Information*

	<i>M</i>	Range
Age	25.45	18–39
Weekly Gameplay Hours	15.46	0–49

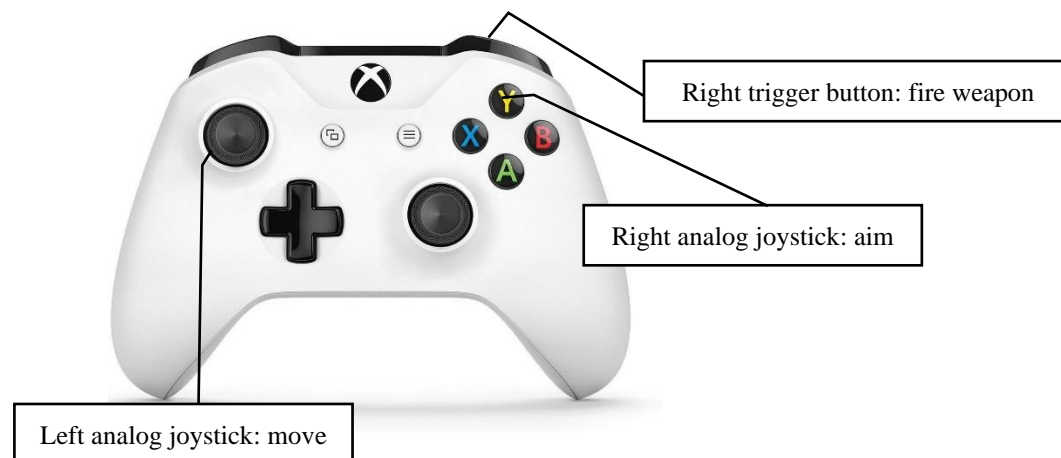
**HOH Sample.** In addition, four HOH individuals (3 males, 1 female) were recruited through the snowball sampling method. These participants were compensated with a Wichita State mug. During the study, three of the HOH participants did not wear their hearing aids and one participant asked to keep them on. The average age for the HOH participants was 33.5 (27–45) with their average weekly gaming hours being 11.25.

## Video Game Task

A 3D, third-person shooter video game was developed with the Unity game development platform (<https://unity.com>). The game was modified from another research study (Vangsness & Young, 2017) and played on a 24-inch monitor. The game is open source and available on GitHub (<https://bit.ly/3b3x3i4>). In this game, players controlled a child who was in a dream where enemy stuffed-animal characters headed towards and attempted to destroy their character. Players used the left analog joystick on an Xbox One controller to move their character around the screen and fired their character's weapon by hitting the right trigger button on the top of the controller (see **Figure 10**).

**Figure 10**

*Gameplay Controls for the Xbox One Controller*



The player's goal was to survive each two-minute level of the game by shooting at and avoiding damage from the enemy characters. Enemies spawned every three

seconds unless there are 30 total enemies already. Players could eliminate enemy characters by shooting them with a toy gun. The player's shots dealt 20 points of damage. Enemy characters dealt 10 points of damage when they touched the player's character. The player knew when their character had been damaged because there was an auditory cue (a groan) and the player's health bar depleted. When the player's health was fully depleted, their character lost one of its three total lives. When a player lost a life, the level timer paused and they waited on a 30-second loading screen. Once they loaded back into the game, their health bar was restored but they had one fewer life. When the player lost all three lives, they proceeded to the next trial. The player's health was restored at the start of each level. Players navigated four tutorial levels and 20 trial levels during the course of the research study. Each experimental session lasted between 60–80 minutes.

### **Figure 11**

*Overhead View of the Barrier Placement*



*Note.* The barrier is indicated by the red line.



**Accessibility Cue Manipulation.** During the game, participants received audio, visual, and/or haptic cues when enemies crossed the barrier (see **Figure 11**), depending on the current cue condition and the side the enemy entered relative to the player character. Specifically, haptic cues vibrated on the side of the controller that marks where an enemy appeared. Visual cue arrows appeared in the center of the screen on the appropriate side of the player (see **Figure 12**). Audio cues consisted of a “monster groan” that occurred on the left side of the headphone when an enemy crossed the barrier on the left and vice-versa. If enemies entered the barrier at the same time the appropriate cues would be given for each one after the other. Cues would only be given once for each enemy. The presence of visual and/or haptic accessibility cues was manipulated within-subject: haptic cues, visual cues, both visual and haptic cues, or no cues blocks. The blocks were counter-balanced using a William’s Latin Square design, which controls for one- and two-level order effects across participants (Fisher, 1992; Wang et al., 2009). The presence of audio accessibility cues was manipulated between-subject to simulate the possible experience of Deaf/HOH players with the no audio group. Approximately half of the hearing participants were randomly assigned to be in the audio group ( $n = 20$ ) and the others to the no audio group ( $n = 19$ ). All HOH participants were in the no audio condition for consistency ( $n = 4$ ).

**Figure 12**

*Visual Arrows Used in the Study*



**Difficulty Manipulation.** Difficulty was defined by the enemy characters' health: higher-difficulty enemies have more health, which requires the player to shoot more times to eliminate them from the screen. A Halton sequence (Chi et al., 2005) was used to select enemy character difficulty levels evenly from a range that spanned from selected using 20 to 400 hit point values (this range was determined through a previous study; Vangness & Young, 2019). Selected values were randomized for each participant using the Fisher-Yates reshuffling algorithm (Black, 2005). Difficulty changed at the start of every level.

## **Procedure**

Participants completed the study in cubicles. After listening to and reading a description of the game, participants completed an eight-minute tutorial at the lowest difficulty setting (20 HP). During the tutorial, participants gained two minutes of practice with each cue condition (i.e., haptic, visual, no cue & haptic/visual combined). Practice cue conditions were presented in the same order as the counterbalancing. Then, participants completed four experimental blocks of the game (see **Figure 13** for a schematic). Each experimental block included five, two-minute levels of randomly-set

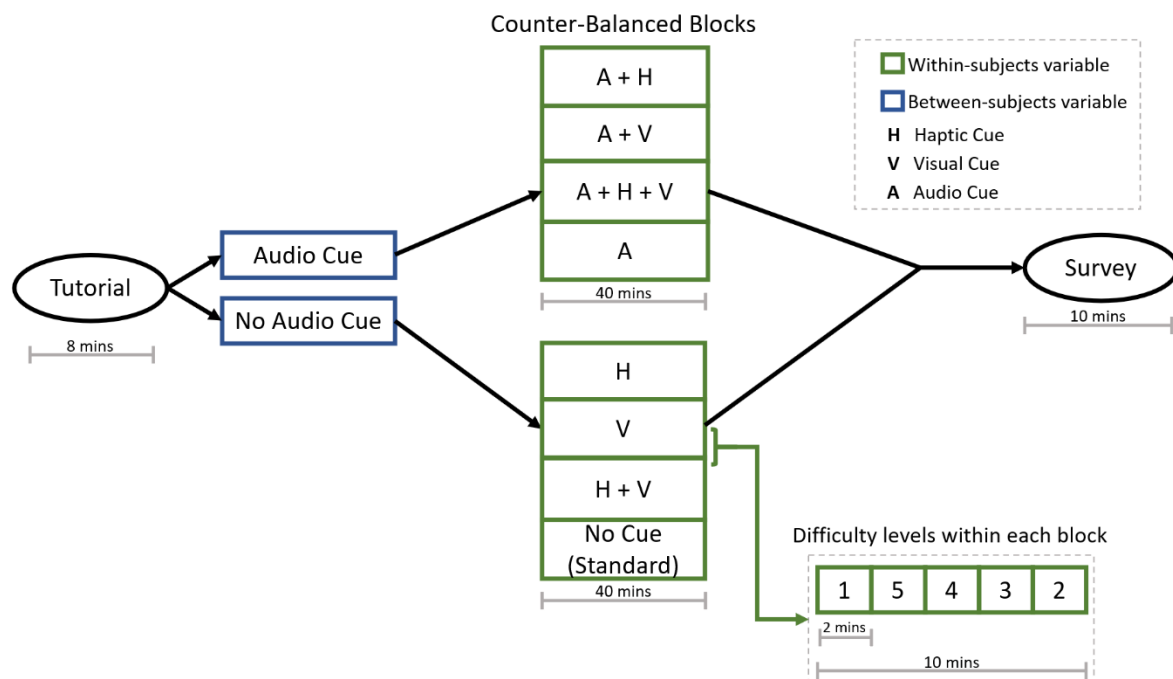
difficulty. Participants saw a new instruction screen describing the cues being used every time a new block began. After the experimental task was completed, the participants took a demographic survey and answered questions about their experiences with the different cues (see

## APPENDIX

APPENDIX). The participants were debriefed, and any questions were answered. This research complied with the American Psychological Association's code of ethics and was approved by the institutional review board at Wichita State University.

**Figure 13**

*A Schematic of the Experimental Session*



**Dependent Variables.** Participants' performance was measured by their rate of damage taken (the amount of damage the player had taken divided by the amount of time that had elapsed since the last enemy touched the player; i.e., attacked). The survey asked questions about the participants' preference for each type of cue with a Likert scale rating (see

## APPENDIX

APPENDIX).

## CHAPTER 5

### RESULTS

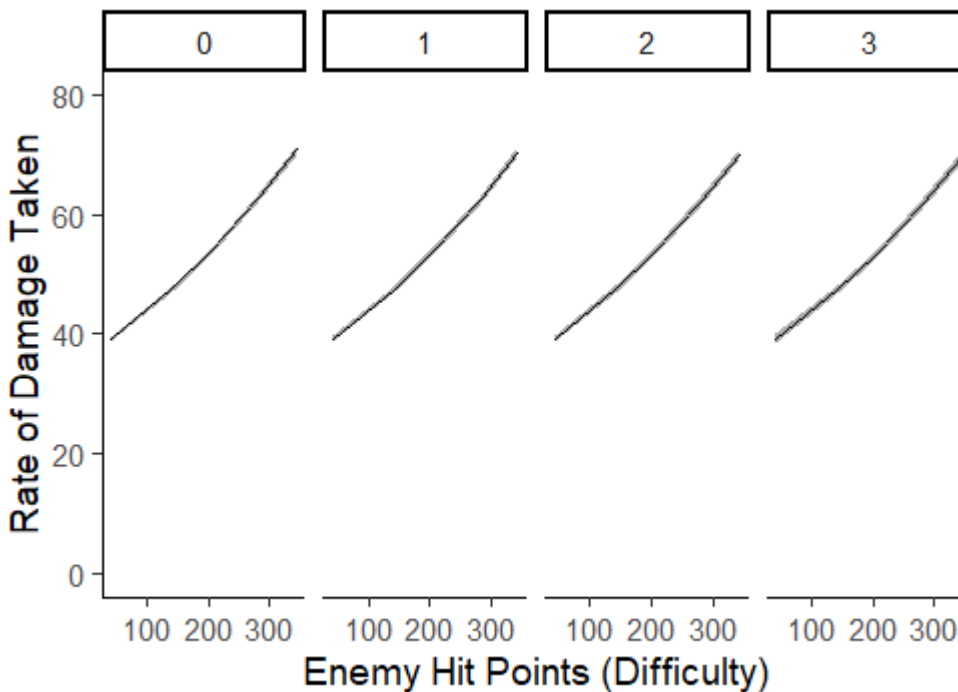
To determine how participant's rate of damage taken (DV) was affected by the number of cues and difficulty (**H<sub>1</sub>** & **H<sub>2</sub>**), a multi-level linear regression was performed. A log-transformed was conducted on the outcome variable to improve the homogeneity of the model residuals. Number of cues was treated as a continuous variable to ease interpretation of the effect. The fixed effect structure included the number of cues and difficulty main effects as well as the Number of Cues × Difficulty interaction. This model also contained hours of video games played per week to control for participants' video game experience. The intercept was included in the random effect structure to further control for individual differences across participants. Number of cues, participant weekly gaming hours and difficulty were means-centered to reduce multicollinearity within the model.

Results of the multiple linear regression (see **Table 4**) did not support **H<sub>1</sub>**; The number of cues did not change participants' performance ( $t = -1.70$ ; See **Figure 14**). The analysis partially supported **H<sub>2</sub>** in that increased workload (enemy HP) decreased participants' performance ( $t = 103.06$ ); however, this relationship was not attenuated by the presence of additional cues; ( $t = -1.11$ ).

**Table 4***H1 and H2 Analysis Results*

Predictor	B	SE	t	95% CI
Intercept	4.06	$1.08 \times 10^{-2}$	374.64***	[4.04, 4.08]
Number of Cues	$-3.75 \times 10^{-3}$	$2.20 \times 10^{-3}$	-1.70	[-0.01, $5.62 \times 10^{-4}$ ]
Difficulty	$1.97 \times 10^{-3}$	$1.91 \times 10^{-5}$	103.06***	$[1.93 \times 10^{-3}, 2.01 \times 10^{-3}]$
Gaming Hours	$2.27 \times 10^{-3}$	$8.51 \times 10^{-4}$	2.67**	$[6.02 \times 10^{-4}, 3.94 \times 10^{-3}]$
Number of Cues $\times$ Difficulty	$-2.32 \times 10^{-5}$	$2.09 \times 10^{-4}$	-1.11	$[-4.33 \times 10^{-4}, 3.86 \times 10^{-4}]$

Note. \* = weak, \*\* = medium, \*\*\* = strong

**Figure 14***Rate of Damage Taken and Difficulty with Number of Cues*

Note. The error ribbon represents  $\pm 1$  standard error.

To determine how participant's rate of damage taken (DV) was affected by cue type (**H<sub>3A</sub>** & **H<sub>3B</sub>**), a multi-level linear regression was performed. The linear regression



included the cue condition and difficulty main effects as well as the Cue Condition  $\times$  Difficulty interaction to control for differences in performance due to task difficulty. This model also contained the main effect of hours of video games played per week (gaming hours) to control for participants' video game experience. Gaming hours and difficulty were means-centered, and cue condition was effect-coded to reduce multicollinearity and allow the model intercept to represent participants' average performance in the game. Damage rate was log-transformed to improve the homogeneity and normality of the model residuals. The results of the analysis are displayed in **Table 5**.

**Table 5***H3 Analysis Results*

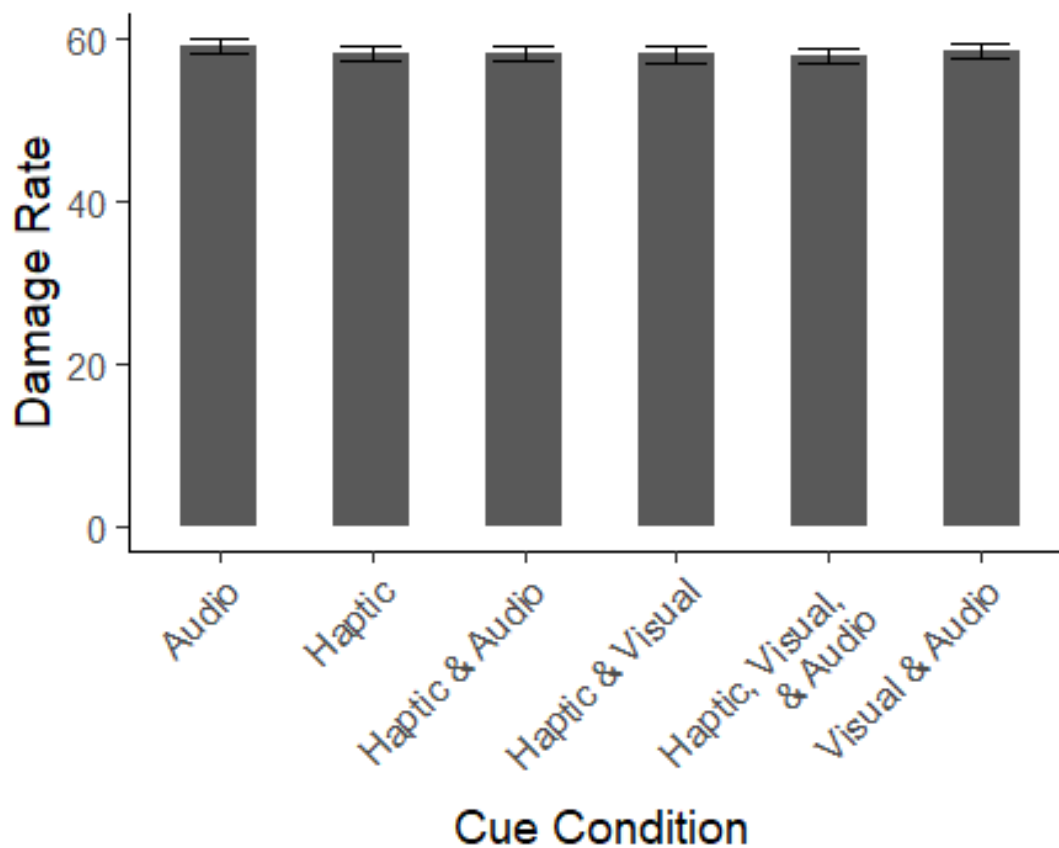
<b>Cue Condition</b>	<b>B</b>	<b>SE</b>	<b>t</b>	<b>95% CI</b>
Intercept	4.06	$1.09 \times 10^{-2}$	371.34***	[4.04, 4.08]
Audio Only	$1.77 \times 10^{-2}$	$1.18 \times 10^{-2}$	1.50	[-0.01, 0.04]
No Cues	$-7.84 \times 10^{-3}$	$1.19 \times 10^{-2}$	-0.66	[-0.03, 0.02]
Haptic	$1.54 \times 10^{-3}$	$1.19 \times 10^{-2}$	0.13	[-0.02, -0.02]
Haptic & Audio	$3.17 \times 10^{-3}$	$1.18 \times 10^{-2}$	0.27	[-0.02, 0.03]
Haptic & Visual	$-1.25 \times 10^{-3}$	$1.19 \times 10^{-2}$	-0.11	[-0.02, 0.02]
Haptic, Visual, & Audio	$-2.64 \times 10^{-3}$	$1.18 \times 10^{-2}$	-0.22	[-0.03, 0.02]
Visual Only	$-1.80 \times 10^{-2}$	$1.19 \times 10^{-2}$	-1.51	[-0.04, 0.01]
Difficulty	$1.97 \times 10^{-3}$	$1.92 \times 10^{-5}$	102.78***	$[1.93 \times 10^{-3}, 2.00 \times 10^{-3}]$
Gaming Hours	$2.13 \times 10^{-3}$	$8.79 \times 10^{-4}$	2.42**	$[4.07 \times 10^{-4}, 3.85 \times 10^{-3}]$
Audio Only x Difficulty	$-5.01 \times 10^{-5}$	$4.56 \times 10^{-5}$	-1.10	$[-1.39 \times 10^{-4}, 3.93 \times 10^{-5}]$
No Cues x Difficulty	$6.98 \times 10^{-5}$	$4.87 \times 10^{-5}$	1.43	$[-2.57 \times 10^{-5}, 1.65 \times 10^{-4}]$
Haptic x Difficulty	$2.48 \times 10^{-5}$	$4.85 \times 10^{-5}$	0.51	$[-7.03 \times 10^{-5}, 1.20 \times 10^{-4}]$
Haptic & Audio x Difficulty	$4.50 \times 10^{-5}$	$4.66 \times 10^{-5}$	0.97	$[-4.63 \times 10^{-5}, 1.36 \times 10^{-4}]$
Haptic & Visual x Difficulty	$-4.01 \times 10^{-5}$	$4.86 \times 10^{-5}$	-0.83	$[-1.35 \times 10^{-4}, 5.52 \times 10^{-5}]$
Haptic, Visual, & Audio x Difficulty	$-3.18 \times 10^{-5}$	$4.60 \times 10^{-5}$	-0.69	$[-1.22 \times 10^{-4}, 5.84 \times 10^{-5}]$
Visual Only x Difficulty	$-8.93 \times 10^{-6}$	$4.94 \times 10^{-5}$	-0.18	$[-1.06 \times 10^{-4}, 8.79 \times 10^{-5}]$

Note. \* = weak, \*\* = medium, \*\*\* = strong

Planned comparisons (See **Table 6**) were conducted and the analysis supported **H<sub>3A</sub>** in that visual cues acted as a redundant display and neither improved nor impaired performance (see **Figure 15**).

**Table 6***H3 Cue Conditions Planned Comparisons Results*

<b>Comparison</b>	<b>B<sub>difference</sub></b>	<b>SE</b>	<b>z</b>	<b>p</b>
Haptic Only vs Haptic & Visual	$2.79 \times 10^{-3}$	0.01	-0.43	.96
Audio Only vs Audio & Visual	-0.01	0.01	-1.72	.24
Haptic & Audio vs Haptic, Audio, & Visual	-0.01	0.01	-0.95	.71

**Figure 15***Rate of Damage Taken by Cue Condition*

*Note.* The error bars represent  $\pm 1$  standard error.

## Exploratory Analyses

A multi-level linear regression was used to determine whether participants' self-reported cue efficacy aligned with their performance in the game (**Q<sub>1</sub>**). The model included the main effects of average rate of damage taken under each cue condition (performance), cue condition, and audio condition, as well as the Cue Condition × Performance, Audio Condition × Performance, Cue Condition × Audio Condition, and Cue Condition × Audio Condition × Performance interactions. 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. Model output is displayed in **Table 7**; specific slope estimates of interest are displayed in **Table 8** and **Figure 16**. Participants who received either no cues (no audio condition/none) or a single cue (audio condition/none, no audio condition/haptic, no audio condition/visual) gave self-reported efficacy scores that lined up with their performance.

**Table 7***Q1 Analysis Results*

<b>Cue Condition</b>	<b>B</b>	<b>SE</b>	<b>t</b>	<b>95% CI</b>
Intercept	3.53	1.91	1.84	[-0.21, 7.27]
Performance	-0.52	1.92	-0.27	[-4.28, 3.27]
Haptic & Visual	-2.66	2.56	-1.04	[-7.68, 2.36]
No Cue	4.19	2.71	1.54	[-1.12, 9.50]
Haptic	0.34	2.47	0.14	[-4.50, 5.18]
Audio	2.13	1.91	1.11	[-1.61, 5.87]
Performance × Haptic & Visual	3.66	2.57	1.42	[-1.38, 8.70]
Performance × No Cue	-4.80	2.71	-1.77	[-10.11, 0.51]
Performance × Haptic	-1.33	2.46	-0.54	[-6.15, 3.49]
Performance × Audio	-2.57	1.92	-1.34	[-6.33, 1.19]
× Haptic & Visual				
Haptic & Visual × Audio	-2.63	2.56	-1.03	[-7.65, 2.39]
No Cue × Audio	-0.42	2.71	-0.15	[-5.73, 4.89]
Haptic × Audio	-1.77	2.47	-0.72	[-6.61, 3.07]
Performance × Haptic & Visual × Audio	3.07	2.57	1.19	[-1.97, 8.11]
Performance × No Cue × Audio	0.48	2.71	0.18	[-4.83, 5.79]
Performance × Haptic × Audio	1.02	2.46	0.41	[-3.80, 5.84]

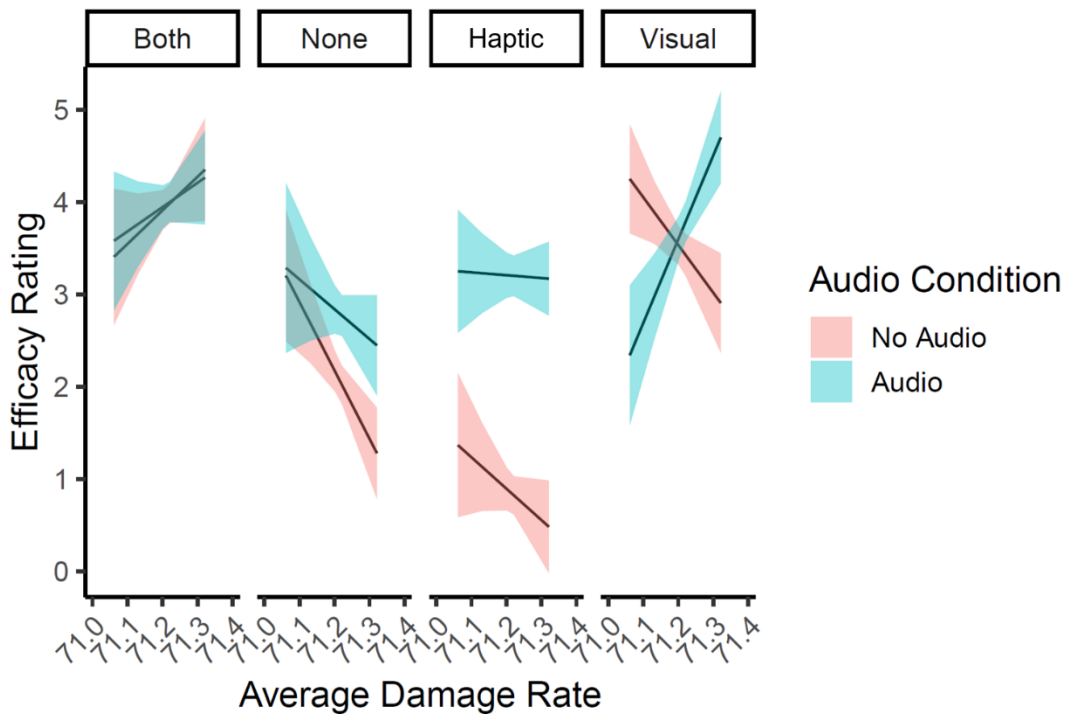
Note. \* = weak, \*\* = medium, \*\*\* = strong

**Table 8***Q1 Estimated Damage Rate Slopes for Each Condition*

<b>Cue Condition</b>	<b>Audio</b>	<b>Damage Rate Slope</b>	<b>SE</b>	<b>95% CI</b>
Haptic & Visual	No Audio	3.64	4.71	[-5.59, 12.86]
	Audio	2.64	4.53	[-6.25, 11.52]
No Cue	No Audio	-7.41	4.34	[-15.91, 1.10]
	Audio	-3.23	5.36	[-13.74, 7.28]
Haptic	No Audio	-3.40	4.65	[-12.51, 5.71]
	Audio	-0.31	3.72	[-7.60, 6.99]
Visual	No Audio	-5.17	4.03	[-13.08, 2.73]
	Audio	9.08	4.52	[0.22, 17.95]

**Figure 16**

*Participant Cue Efficacy Ratings and Performance by Audio Condition*



*Note.* The error ribbon represents  $\pm 1$  standard error.

Finally, trends in participants' self-reported most preferred cue were used to answer **Q<sub>2</sub>**. The haptic and visual cue condition was hearing participants' most preferred cue condition in both the audio (9) and no audio (8) conditions. HOH participants' most preferred cue condition was the no cue condition (See **Table 9**). The number of HOH who picked the no cue condition was a higher proportion compared to hearing participants who chose the no cue condition.

**Table 9***Participants' Most Preferred Cue Condition*

	<b>Haptic</b>	<b>Visual</b>	<b>Haptic &amp; Visual</b>	<b>No Cue</b>
Audio	20%	30%	50%	0%
No Audio	6%	33%	44%	17%
HOH (No Audio)	0%	25%	25%	50%

**Thematic Analysis**

A thematic analysis was conducted on responses to the free-response question about why participants preferred their selected cue condition. Thematic analyses are useful to develop and report patterns of meaning in a thematic form (Larkin et. al., 2006). The thematic analysis identified four themes of 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 10**). 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 were the most reported cue that provided directional information about the enemy character's location. Many participants reported that the no cue condition did not provide enough information. A few participants reported that having the cues together allowed the cues to make up for each other where one may lack.

**Table 10***Themes from the Thematic Analysis*

<b>Cue</b>	<b>Theme</b>	<b>Count</b>
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
	Provided directional information of the enemy's location	17
Visual	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



## CHAPTER 6

### DISCUSSION

#### Hypotheses

The analyses revealed that additional cues had little impact on participants' performance, refuting **H<sub>1</sub>**. Even though the cues did not impact participants' performance, participants still displayed strong preferences for cues. Most participants chose the combination of haptic and visual cues as their preferred condition and very few participants chose the no cue condition. This demonstrated that participants preferred cues, even though those cues did not improve their performance.

Although increasing the difficulty of the video game decreased participants' performance, the addition of cues neither improved nor impaired participants' performance. This could indicate that all of the accessibility cues were equivalent to one another in the amount of information they provided. Alternatively, it could suggest that the cues were ignored; however, the qualitative data suggests otherwise. Participants reported visual cues as one of their favorite cues. Together, this data suggests that cues were not important or used by participants in this video game, but they did impact their gaming experience. This could be because of the simple type of video game used for this study. If a more complex video game was used, the results might be different.

The results revealed that hearing and HOH participants' preferred cues sometimes aligned with their performance in the game. Participants were able to accurately rate the efficacy of no cue condition to reflect their performance. Additionally, the no audio condition of haptic only and visual only conditions efficacy scores lined up

with participants' performance. These findings are interesting and merit potential investigation in the future.

A larger proportion of HOH participants stated that the no cue condition was their most preferred compared to hearing participants. HOH participants' preferences trended in the direction of the no audio group but differed from the audio group. These trends are noteworthy, but more HOH participants are needed to evaluate whether this is a real difference or the result of a small sample size.

## **Literature**

The results of this study contribute to the literature discussed previously. MRT predicted that because a video game environment takes up an abundance of visual capacity, utilizing another channel (i.e., haptic or audio) would increase performance as compared to adding to the same channel (i.e., visual; Wickens, 2002; Wickens et. al., 2015). Redundant displays predicted that additional cues would not impair performance and unhelpful cues would be ignored (Ng & Nesbitt, 2013). Because none of the cue conditions had an impact on participants' performance, a reasonable guess can be made that the cues were ignored; however, qualitative data collected shows that this is not true. Participants had strong feelings about each of the cues and most felt positive about the visual cues, specifically. This is an interesting finding and could mean that the cues were not salient or useful enough to affect the participants' performance. The qualitative feedback does confirm that participants preferred redundant cues because many felt that some cues could make up for each other where another cue lacks. This is important when we think about how some individuals think that accessibility options can "dumb down" games. 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.

### **Limitations and Future Directions**

This study was a first step in looking at directional cues in the context of a video game; therefore, the video game was very simple, and the results should not be generalized to all video games. A more complex video game should be used for future studies to explore directional cues in these environments. Additionally, the video game used was a third-person shooter in a 2D space. Future studies could explore cue use in different types of games (e.g., first-person) and in a 3D space.

Many participants mentioned that the binary nature of the visual cues (right and left directions only) was confusing, and they would have preferred an omnidirectional notification. The binary cue was originally picked to ensure all cues could be equal and haptic cues were only able to be given in a binary fashion. This was a limitation of the technology, but future studies should explore giving these cues with a device that is capable of omnidirectionality. The technology also was not created with distinctive right and left haptic cues in mind and participants noticed this. Some participants mentioned that they were unable to differentiate between right and left audio and haptic cues. Both right and left cues were so similar that some participants did not notice that they were different directional cues. This limitation could have contributed to the lack of performance difference between the cues. Future studies should investigate using a device capable with more distinct haptic cues (e.g., PlayStation 5 controller).

Preferred cues did not always align with participants' performance, but this study did not further investigate why this occurred. Future studies could further investigate this trend and explore which factors influenced these results.

This study had a very small sample of HOH participants and no Deaf individuals. The HOH individuals in the study were all placed in the no audio condition. This study took place during the COVID-19 pandemic and recruitment for specialized populations was difficult. Future studies should recruit more Deaf/HOH participants.

## CHAPTER 7

### CONCLUSION

This study tested the efficacy of accessible cues that can be used by hearing and Deaf/HOH individuals while playing a video game. Haptic and visual cues were investigated because of their potential to provide directional information without requiring hearing. Using a controller to provide haptic cues is an easy and inexpensive way to provide accessible alternative cues. It would not require any additional purchases from the consumer, and it would utilize technology most gamers already have.

Results from this study indicated that haptic, visual, and audio cues did not have an impact on the participants' performance. This could indicate that the cues were not helpful enough in this type of video game and/or that haptic cues may perform as well as audio and visual cues. Even though cues did not impact hearing participants' performance, hearing participants preferred to have all the cues available to them when playing the video game. Qualitative data showed that most participants liked all the cues together because they could make up for another cue that was missed. Participants' preferred cues sometimes aligned with their performance in the game.

In conclusion, accessibility cues seem like a potential new accessibility feature, but they should be tested with more types of video games. Participants' preferences do not always align with their performance. HOH participants' performance looked similar to hearing participants' performance; however, only four HOH participants participated in this study. Future studies should expand upon this data and consider the limitations of this study.

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## APPENDIX

## APPENDIX

### Study Questionnaire

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#### Demographic Questions

1. How do you identify?
  - a. Male
  - b. Female
  - c. Nonbinary
  - d. Other
2. What is your age?
3. How would you describe your hearing ability?
  - a. Deaf/deaf
  - b. Hard of Hearing
  - c. Hearing
4. Would you describe yourself as a gamer?
  - a. Yes
  - b. No
5. How many hours a week do you typically play video games (Type in zero if you don't play games)?
6. What systems do you play video games on? (Select all that apply)
  - a. None
  - b. PC
  - c. Console (Xbox/PlayStation/Nintendo)
  - d. Handheld (Switch/3DS)
  - e. Mobile
  - f. Virtual Reality (VR)

#### Audio Group Question Set

1. How effective were the Tactile and Auditory cues alone?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  2. How effective were the Visual and Auditory cues alone?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  3. How effective was having only Auditory cues?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  4. How effective were the Visual, Tactile, and Auditory cues together?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
-

5. Which cue(s) did you prefer?
  - a. Tactile
  - b. Visual Arrows
  - c. Both Tactile and visual arrows combined
  - d. None
6. Why did you prefer that cue(s)?
7. Any other comments about the study?

**No Audio Group Question Set**

1. How effective were the Tactile cues alone?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  2. How effective were the Visual cues alone?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  3. How effective were Visual and Tactile cues together?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  4. How effective was having no cues?
    - a. Likert: Not Effective 1 – 7 Extremely Effective
  5. What cue(s) did you prefer?
    - a. Tactile
    - b. Visual Arrows
    - c. Both Tactile vibrations and visual arrows combined
    - d. None
  6. Why did you prefer that cue(s)?
  7. Any other comments about the study?
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