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Introducing the Gamer Information-Control Framework: Enabling Access to Digital Games for People with Visual Impairment

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ABSTRACT

In this paper, we present a foundation for understanding the elements that enable people with visual impairment to engage with digital games. This is defined by the gamer's relationships with information and with elements of control provided by the game, and is mediated through in-game metaphors and affordances when gamers interact as users or creators. This work complements previous research exploring the points of view of gamers with visual impairment by focusing on the games they play and prioritising the relationships between the key enablers of access to digital games. Using the framework to examine existing and missing components will enable designers to consider broader aspects of accessibility in game design.

Author Keywords

Visual impairment; digital games; audiogames; control; information; framework

CCS Concepts

•**Social and professional topics** → **People with disabilities**;
•**Applied computing** → *Computer games*;

INTRODUCTION

With two out of three Australians playing videogames, and an estimated 2.5 billion videogamers around the world [18, 88], it is important that digital games be made accessible to all regardless of physical abilities. The visual nature of digital games —embodied, literally, in the name videogames [10]— renders them mostly inaccessible to people with visual

impairment (PVI). This produces feelings of exclusion [79,94] and of "being left in the dust" [6].

Current research on games for PVI typically focuses on the introduction of a single game as a case study in which researchers present the game to gamers with visual impairment (GVI) and evaluate its use. *Shades of Doom* [90], *Blind Hero* [93], *PowerUp* [84], *Swamp* [8], *VBGhost* [55] and *BraillePlay* [56], are some of the games that have been introduced in this manner. This approach has generated many games that offer ongoing enjoyment to GVI. However, to identify the common elements that make a game accessible or prevent access to it, a broader understanding of such elements is required. Works such as that of Urbanek [85] and Andrade et al. [6] represent attempts to take a broader look at games for GVI. Nonetheless, these works focus on describing the experiences of GVI rather than on reflecting on the common elements that enable and support access.

In this paper, we propose a framework for understanding the elements that enable PVI to access digital games. We show that gamers' relationships with the information provided by the game, and with elements of control, are key to enabling access to digital games for PVI. These relationships are mediated through in-game metaphors, and extend beyond play to encompass creation activities. With this framework, we provide a broader way of thinking about design of games that are accessible to PVI. Our approach is independent of the game being studied, has been developed through an inductive process, and has been informed by in-depth semi-structured interviews with expert GVI.

This work continues the move away from a deficit-driven approach to understanding games towards a more positive approach which embraces and respects the voice, lived experience, and expertise of PVI [6, 57, 67]. It explores the relationships between the different elements that comprise the gaming experience of PVI. In doing so, our work recognises how the elements of game design influence our understanding of the complex, nuanced requirements of disability and ac-

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cess [72, p. 72—75]. This approach allows HCI researchers to focus on designing and understanding interactions, removing the need to appropriate technologies as well as physical and other impairments, as is the case when researchers attempt to emulate the experience of PVI [14, 67, 73].

AIMS AND CONTRIBUTION

The main contribution of this work is the presentation of a framework to understand the elements that enable people with visual impairment to access digital games. These include two key relationships and a set of in-game metaphors that support these relationships. Whereas previous research has provided an overview of games commonly played by PVI [49], or has explored the opinions, habits, and concerns of GVI [6, 85], to the best of our knowledge this is the first attempt at providing a broader exploration of the elements that enable PVI to access digital games. With this research, we aim to provide a tool for game designers and researchers to think about the key relationships that enable PVI to access digital games. The elements of this proposed framework are derived from interviews with expert GVI that recognise their knowledge and skills developed through lived experiences of disability and gaming, thus advancing empowerment approaches over deficit/compensation perspectives [58, 67, 72].

LITERATURE REVIEW

This work builds on current understanding of games, gamers and game play through a nuanced discussion of the gamer's dual role as player and as (potential) creator or co-producer. It builds on prior work with GVI and understanding of disability, as well as broader HCI contexts of affordances, metaphor, materiality, and embodiment, and is situated in the study of games and play.

Disability

There has been recent interest in HCI in the needs and practices of GVI [6, 29, 85] and, more broadly, of PVI [21, 33]. This work raises questions of inclusion and empowerment [71] and examines the challenges faced by different groups and the technologies that support and enable them. Our framework describes the relationship between the player and the real-world tools that may be adopted and appropriated as in-game metaphors. In particular, we consider the representation of echolocation as an in-game metaphor.

Echolocation

Echolocation is a technique that combines production of sounds with an understanding of how those reverberate over surfaces and the time delays of the echoes produced to create a mental image of the physical surroundings [5, 50, 77]. Like bats and some aquatic mammals [81], up to 20-30 per cent of people with visual impairment can use echolocation as a tool for depth perception and navigation as well as for understanding the properties of specific objects [77, 80].

Although there has been some exploration in literature of games and game-like tools for teaching echolocation [23, 91], and on the use of echolocation to provide additional in-game context —Haahr [37] describes a game for sighted players in which the player takes the role of a blind character who

must use echolocation— there has been comparatively little research attention on the use of echolocation as a supplementary or alternative in-game method for navigating game spaces. Preliminary studies [5, 91] have shown that PVI can successfully locate specific targets in virtual worlds through a combination of pre-recorded and dynamically-generated echoes and bin-aural sound. The player's relationship with in-game tools for echolocation is a core element of our model.

Games

Audiogames

An important genre of digital game that enables play by GVI is audiogames. These games feature "complete auditory interfaces, so that they can be played without the use of graphics" [34]. Audiogames use earcons, abstract artificial sounds or sound patterns with varying metaphors and levels of articulatory directness [31, 42], to convey information to players. Unlike videogames, which frequently feature similar interface elements and metaphors to represent objects and actions, there is no consistent set of earcons used across different audiogames, even for common tasks such as saving a game or confirmations [6]. Players must learn a new set of earcons as they learn a new game [34]; this increases the cognitive load involved in play as the player must focus on understanding these signifiers rather than on the potential for controlling novel and creative actions that they may [be intended to] afford.

MUDs

Text-based MUDs, or Multi-User Dungeons [10, 12, 75], are another popular choice for GVI. Because these games provide information and are controlled through text, they represent an accessible option, despite not being specifically designed for PVI. Spiel et al. [75] identify a number of opportunities to improve the accessibility of these games for GVI. Specifically, they found differences in the ways in which sighted players and GVI used in-game navigation systems in different types of spaces, with GVI generally preferring egocentric systems which represent directions in relation to the player (go forwards, turn right) and sighted players preferring systems which referenced cardinal directions (go north, west, etc). These findings highlight the importance of the relationship between the player as user of the game and the game's controls, even on text-based interfaces.

Affordances and Metaphors in digital games

The affordances of an object are the "potentials for action" that a user can perceive [35]; an affordance is a relationship between a person and an object [60]. Interfaces are said to have *perceived* affordances. Elements of digital games afford a specific range of in-game actions, for example, jump / pick up item / open door / fight / move in a particular direction / use item. Signifiers — such as a door handle, 'enemy' icons, compass arrows or a bag — communicate potential behaviours to users [60]. When these are clear or familiar, the cognitive load on players is reduced, but poor or non-existent communication, or an overly-literal metaphor, complicates or obscures the potential for action [59]. Moreover, a game communicates "social affordances" [28] or possibilities of interaction with other players, and may present "motivational affordances" that

satisfy the player's need for competence, autonomy, or relatedness, the core elements of Self-Determination Theory [13, 30]. As digital games rely on the visual sense to display signifiers — hence the name "videogames" — these signifiers and the affordances they embody may be lost to those who cannot see unless they are explicitly communicated to PVI [6].

Similarly, there are largely-unexplored tensions around the use of interaction metaphors in digital games [68]. Norman [59] notes that there are risks in adopting overly literal metaphors — for example, they may unnecessarily restrict the scope of interactions and limit creativity in design [36] — yet at the same time these literal metaphors "require very little explanation to users" [74]. Successful metaphors simplify the relationship between a player and a game in both accessing information and in operating, or controlling, the game by communicating affordances to players.

The absence of a consistent set of design conventions for audiogame design complicates and problematises the processes of both play and production, as it relies on the player to perceive the affordances of each situation without the benefit of prior experience with common metaphors. Moreover, it requires the designer to develop not only new interface elements but also new signifiers. Without a common set of interaction metaphors, the affordances and signifiers of each audiogame must be identified and learned before the player can proceed or advance. This creates distance between the signifier and the player [57], interrupting the player's sense of presence and immersion [53] and disrupting the potential for "instant sense-making" [38]. Further, it disrupts the relationship between player and game, disabling the player through the breach. This contributes, we believe, to players' criticisms that accessibility measures may also serve to unacceptably reduce game complexity [6].

Co-production — Players as Creators

Players and developers hold similar ownership of the game, with content creation by gamers helping to keep games fresh [41, 43, 62]. Through play, players create new information within the game-world. For example, they may move or remove objects or barriers, creating a new configuration of existing objects within the game space. Moreover, like sighted players [9, 62], GVI may take an active role in co-creating in-game content and are active in creating entirely new games [76, 85]. To date, there has been no research into the experience of GVI as creators of either games or game controllers.

HCI Contexts

Materiality and Embodiment

Playing a game is an embodied experience [46, 47]. The player interacts directly at an operational level with the game and its controller [26]. They are embodied as an in-game character [26] with the experiences and action potential of that character in a given situation [46]. For example, Haahr [37] describes a game for sighted players where the character that they play is blind. This requires the sighted player to take on the attributes of that character, navigating the game by echolocation rather than by sight. Similarly, GVI may be simultaneously sighted and non-sighted based on the attributes of the character that they control. This represents a design challenge, particularly

where the 'sighted' character's impressions and observations in a 3D space must be communicated and presented to a non-sighted operator. The player's body receives and mediates information and acts to control the game environment, and the game's inability to accommodate the bodies and abilities of GVI disrupts the experience of play.

In creating games, the material, operational properties of the game controller, in combination with the computational properties of the system, enable and prohibit in-game affordances for individual players [44]. Interaction in digital games for PVI has relied on the use of a keyboard [69, 93]. However, recent research has explored the use of mainstream game controllers to embody the interaction with a digital games, with positive results [25, 79].

METHOD

We conducted qualitative, semi-structured interviews for data collection, and used thematic analysis for data analysis. Our analysis focused on exploring the key relationships that enable the gaming experience of PVI. This study received Ethics approval from the University's Ethics Committee (Ethics ID 1851274).

Data collection

Data for this research was collected through online semi-structured interviews with a group of six GVI over the period of a week. These semi-structured interviews aimed to provide an in-depth exploration of relations between GVI and digital games. Questions asked during the interviews included: the type of games participants played, participants' opinions on existing metaphors employed in digital games targeted to PVI, their thoughts on the relationships between digital games and the computer systems where the games run, their experience creating audiogame-related content, and their perception on the challenges they face when engaging with digital games — both mainstream and targeted to PVI. Interviews were conducted over the internet, using the software participants felt most comfortable with. Five participants used the video-conferencing software *Skype*, and one participant preferred the audio-conferencing software *TeamTalk*. Interviews were audio-recorded and were scheduled to last for 20 minutes, however some participants chose to exceed the pre-established time limit to more fully express their views on their experience of gaming as a PVI. Interview recordings amounted to 186 minutes in total or 83 pages of transcribed material.

Participants

Participants were recruited through posts on forum.audiogames.net, an online forum for that attracts a large number of GVI. A total of six participants agreed to take part in an interview. These participants were over 18 years of age and had a visual impairment that could not be corrected with glasses: blindness with or without light perception, or low visual acuity with mostly colour perception. All participants had been playing audiogames or MUDs five years or more, and spoke English as a first or second language. Four participants identified as male, one as female and one preferred not to disclose their gender. As participants were self-nominated, we were unable

Table 1. Demographic information of participants.

N	Age range	Name	Gender	Country	Impairment (and onset)
1	18 to 25	Juan	Male	Canada	Blind, no light perception (from birth)
2	18 to 25	Marcela	Female	Philippines	Blind, light perception (early childhood)
3	26 to 35	Alberto	Male	Brazil	Blind, no light perception (early childhood)
4	26 to 35	CJ	Prefer not to say	USA	Blind, no light perception (10 years old)
5	18 to 25	Carlos	Male	Austria	Blind, light perception (from birth)
6	26 to 35	Jose	Male	USA	Low visual acuity. Colour perception. Loss of peripheral vision (from birth)

to control for gender bias. Table 1 shows a summary of our participants, who are referred to by pseudonyms.

Data analysis

Data were analysed using inductive thematic analysis, as described by Braun and Clarke [19, 20]: we initially transcribed the interviews, read and re-read their content, and established initial codes based on what was present in the data. Upon finishing this initial coding, we identified several categories or themes within the data. These initial themes were given a formal definition and a name. The first author coded data from all the interviews and the other authors coded specific interviews. This was done to ensure consistency amongst the themes established. Although different authors named individual themes differently, they identified similar concepts and ideas, thus showing agreement.

Importantly, thematic analysis is about the quality of the codes rather than about their frequency. A single instance may constitute a valid code, which then combines with other codes to generate a theme. Key themes in our data highlighted the important relationships that enable or prevent PVI to access digital games. [57]. We identified two key types of relationships that enable GVI to access digital games, which occur both when the gamers are playing (using) digital games and when they engage in creative activities.

FINDINGS

In this section, we present the themes found as part of our thematic analysis. For findings regarding the types of games GVI played, the average duration of their gaming session and the genres they played, see [6]. The themes we identified mostly reflect representations of 3D space, representations of real-world objects and phenomena (radars, white canes, footsteps, echoes, spatialised sound, echolocation and walls), text as a means to convey information and control the game, and other enabling tools. Participants reflected on the nature of computers as complex systems, the metaphors they would like to see implemented in games and their previous experience engaging in creative activities related to digital games.

Representation of 3D space

Representing and understanding 3D space has proven challenging for GVI. According to Juan, who lost his sight during childhood, it is because *"we don't have that kind of... we don't think that way, most of us"*. Marcela explained how 3D games are presented to GVI:

"In the blind community when we say 3D games, it means that you can walk up and down the map, unlike side scrolling games, where you only walk to the sides. . . In 3D games, you can use the four arrow keys to go through the map."

3D space in games may be demarcated by natural features, such as dense forest or precipices, or by 'built' elements such as walls and buildings. These determine where players are able to go and the routes they can take within the game.

For Marcela, the controls used in games that try to represent 3D space are a source of frustration. She said: *"One thing that I don't like sometimes with the 3D game is that instead of using arrow keys, they use A, S, D, and W. I want the 3D games to use just four arrow keys rather than other keys"*. Representations of 3D space in games targeted to GVI seemed to limit players to four-directional movement, which was frustrating to some participants. Further, the controls provided in games are not appreciated by all gamers, particularly when a game requires players to learn a new set of controls (here: the A, S, D, W keys for movement rather than the more usual arrow keys).

Representation of real-world objects

Metaphorical representation of physical objects such as radars, tiles, white canes, footsteps or walls, were described by participants as means to convey in-game information. The game leverages the player's experience and expectations of comparable physical objects in its implementation of these tools, although the outcomes do not always align with real-world outcomes.

Radars and white canes

Juan, Carlos, JC and Marcela described the use of radar-like systems for navigating audiodames. Their description focused on the radar system provided by games like *Swamp* and *Crazy Party*. CJ explained the operation of the radar as follows:

"You can point it any direction, but it will scan five tiles or so. A tile is not incredibly defined as how big it is. It's basically how far you're going to step. You can adjust the range on it, so it could be just a few tiles ahead or it could be a lot further."

Carlos and CJ described the radar system akin to a "virtual cane", and Juan added that *"you can turn in 45 degree increments as well, 360 degree if you have a mouse"*. Additional functionality of the radar system included tracking the position of other players. Marcela described this use of the radar system when talking about the MMORPG *Swamp*: *"If you add the*

characters to your party, you can hear a beep to your leader of the party. So, you can always know what is the direction the leader is going, and you can use a radar to know how far are the members from each other". Tiles, radar systems and white cane-like approaches provide GVI access to information about elements of the game world that are not immediately adjacent to their in-game position.

Footsteps and their echoes

Several audiogames use echoes to signify the presence of physical features such as walls, precipices or open spaces. Carlos described how such echoes are implemented: "Mostly platformers use this. They signify that there is an edge by echoing your footsteps or by putting an echo near a wall". Jose, Juan and Alberto provided similar descriptions for the echo system and they identified the first-person arcade games *Sarah and the Castle of Witchcraft and Wizardry*, *Shades of Doom*, and *Planet Saga* as examples of games that use echoes to signify proximity to either a precipice or a wall. Alberto described the effect in *Sarah and the Castle of Witchcraft and Wizardry* as follows: "when you're walking next to a wall for example, and we have an opening you have an echo towards the direction that the opening appears. So, you can turn away without bumping on the next wall". Juan added that "in wide open spaces, you'll hear extra footsteps around you, just [to] sort of let you know that it's a wide-open space".

The use of echoes as a metaphor may not be akin to what occurs in the real world; however, these examples show that they are used to convey spatial information. Here, the same metaphor (the echo) signifies two distinct—and opposite—features. open spaces and walls have different effect on player characters, as one precludes and the other may encourage movement in a particular direction.

Representation of real-world phenomena

Participants described how real-life sound phenomena such as spatialised sound and echolocation are represented in videogames for GVI.

Spatialised 3D sound

This type of sound is used to approximate the human experience of sound in the real world as a player moves through or exists within a digital space. The appeal of this approach varied: for CJ "[Spatialised 3D] recordings, those are usually really good, but you try to use the same effect in games, it's usually really not that good... it felt like they fell into the uncanny valley". However, Jose thought differently; he "enjoyed the games themselves, the environments and the way the sounds moved around you realistically as if you were actually there". He thought "that was very cool". These descriptions show that the relationship between GVI and 3D sound as a conveyor of spatialised information is experienced differently by each individual and may depend on the context.

Echolocation

Echolocation is the capability of some mammals, including humans, to use sound pulses and echo reverberations to create a mental picture of their surroundings [5, 50]. Our analysis showed that participants made a clear distinction between echo systems (described above) and echolocation capabilities.

This is a strong metaphor with profound connections to PVI's experience of echolocation in the physical world, which participants would like to see implemented in games. Nevertheless, they have some concerns about how this would be realised.

Jose, CJ, and Alberto use echolocation to an extent. CJ recalled their early experiences with echolocation: "I had no idea what was actually going on, how this was working, but that was kind of always the thing that sort of got better over time", as well as later, more confident use of echolocation: "when I was in college, I started to notice that I was able to tell where things were better if I was actually using the cane right.". Jose recognized that "the real problem with [echolocation] isn't just that you just hear sounds bouncing off things, is that you have some things that will block sounds too. It seems like something that would be really complicated for the computer to do".

The echolocation metaphor may provide GVI with additional valuable information about the game world as it does in the physical world. However, participants are aware of the technical difficulties of implementing this technique and of the skill required to master echolocation. Like other information sources, echolocation's utility is driven not only by the information to be conveyed (setting) but also by the user.

Game accessibility and assistive tools

Complex relationships exist between GVI and the devices that allow them to play digital games. Our participants described the complexity of computers and the relevance of alternative hardware solutions to mediate orientation.

Software interplay

Within the already complex architecture of the gamer's computer, the interaction between their accessibility software and the games is critical. Alberto noted that he liked "to have the screen reader on at all times, because if I need to alt-tab to see another window and talk to someone else I can just do it". Carlos explained that certain games do not work with specific accessibility software: "that is an issue of the screen reader itself because the screen reader, JAWS takes the keys and then steals the keyboard away from the application, so the game can't actually be played with it on". He also pointed out that this issue was more common in older games. In the case of Marcela, her first computer game "actually is [a] game for JAWS". This has modelled her gaming habits. She said: "As much as possible I look for games that work with JAWS... Maybe it's because JAWS was the first screen reader that I used". Accessibility software is an important factor of the overall gaming experience, as this software enables a person with visual impairment to control their computer—but this relationship is disrupted when a game is incompatible with a player's preferred accessibility software.

The complexity of the computer systems used by GVI was evident when Alberto explained how he communicated with other gamers: "We tend to use means outside the game to [communicate]. We actually use Skype to, say for example 'let's regroup at the safe zone of map three, and let's explore from there'". This exemplified the complex interplay between player, screen-reading software, game, audio-conferencing

software and the computer's sound system. Additionally, CJ described risks of this complexity and stressed the importance of having games that run smoothly. They mentioned: "[the game] has to be able to work smoothly and stuff. If it's going to lag or crash all the time on my system, that's going to be a problem". Dourish [32] observes that computers are themselves prone to obsolescence and aging, and that software itself can be ephemeral in nature. The practices of GVI are therefore materially contingent upon the complex assemblages of computers and sub-systems that they require.

Alternative hardware solutions

Hardware solutions to improve perception of spatialised information are available. Participants commented about the SeeMonkey device. Alberto described this device as follows: "the goal of SeeMonkey is to connect to your headphone so the game can track where the direction you're looking at". His view on this device was that "if we can add this technology to an audiogame, we can emulate vision, sight. Because, we can have your character looking towards West for example, and the sounds from the other directions will be lowered". CJ was also familiar with the device, and added "the only real problem with it is keeping it calibrated... It had this tendency to drift really easily". In CJ's opinion, the combination of 3D binaural sound and head-tracking:

"might work better, because one of the main things that was a problem with the more keyboard-controlled games is just orientation. You would turn and then you would run into a wall, and then you would try to turn to get around it, and you would have no idea what direction you're actually facing."

Participants recognised that mechanisms that would enable control of the game beyond the keyboard could improve orientation in games and convey valuable spatial information to the player.

Making digital games more accessible

Participants identified a series of small changes and achievable targets that could create a big difference in accessibility in games. According to Jose:

"when you're actually giving yourself a realistic target, you're still going to give blind people significantly more enjoyment in the game. People that really enjoy the game already, or even just enjoy listening to videos of it and playing it as much as they possibly can, are going to appreciate every single thing you do more than you might think."

Alberto mentioned the following additional metaphors: "Coordinates are good for blind people, so are beacons... you can face the sun and that makes a tone if you're facing it and there's also a compass [mechanism]". Making text in menus accessible to screen-reading software was mentioned by Jose. Similarly, Carlos, who has more experience with MUDs mentioned: "all you really need to be able to play is a way for you to read the text, be this through self-voicing or SAPI or a screen reader". Other ideas included "audio cues to the meter bars like Ultra Street Fighter Four ... collision sound when you bump into a wall or objects" (Alberto), "ways to

turn down music and make action scenes a little less chaotic so there's not a million different things" (Juan). Participants have signaled the need for ways to convey more information and to have more control over the flow of information provided by the game.

Text as an interaction mode

Out of our six interviewees, Carlos and Jose had the most experience playing MUDs, with Jose "playing a MUD called Discworld MUD for well over 13 years". Jose described his experience in Discworld as follows:

"The MUD is enormous. Including the terrains, I believe the MUD has over a million rooms. Some of the cities are quite large as well, which can make it difficult to find your way to where you want to go. After about 13 years of on and off play, though, it's not a problem for me anymore. I've built up mental maps of city layouts, where certain points of interest are, and some of the roads between cities."

Jose's comment highlights how even relatively simple text-based games can foster long-lasting relationships of engagement while comprising a complex network of rooms, commands, cities, roads and more.

What attracted Carlos to MUDs was replayability: "if you want replayability and explore multiple facets of a story, then a text game is usually the better option"; and the ability to create the entire world with his imagination. "MUDs also draw a lot more on your imagination because it's just text. So you can imagine what the world feels and looks and sounds like". Similarly, Jose added that MUDs "really opened my eyes to the level of writing people could do that were just not professional writers". Carlos noted that "audiogames can be very fast paced and you don't really have that option with MUDs unless you have a sound pack". The appeal of MUDs may be due to the gameplay occurring entirely in the player's heads.

Not all our interviewees were fond of MUDs. Marcela said she doesn't "like dealing with MUD client... Because there's a lot of typing in the game". CJ commented they "would rather have a good audiogame" than a MUD. Marcela's and CJ's comments highlight some of the limitations of text-based interfaces: the need to learn specific commands to exercise control of the game, and players' preference for one form of control interface over another.

Gamers as creators

Some participants described engaging in the creation of games and game elements. For instance, Alberto said: "I'm part of a small team called Blind Gameplay, and we try to make our own versions of some games. I also do a bit of voice acting for some [audiogames]". CJ described their engagement on creative activities: "There was a time when I was trying to figure out how to make [3D binaural recordings]. I think it actually all started with... I was making some kind of audio scene and there was this part where I wound up kind of testing out some effects". Additionally, participants have explored the

use of tools for creating digital games. Carlos provided rich insights on the programming language *BGT*:

"BGT was made by a dev called Philip Bennefall. It stands for Blastbay Game Toolkit. It's a language based on Angel script, which is not that hard to learn and there's a lot of blind people programming games with it. It's supposed to be only for games, but it uses a very old form of audio input, so you don't really have many options for this. You can only change the pitch and the volume and the patterning of the sound. You don't have any effects like HRTF¹ or anything."

Carlos' description of his experience with *BGT* shows the potential role of GVI as game creators. Carlos finished by voicing his frustration around other game development tools and his aspirations for accessible game development tools:

"I mean many people are now migrating to Python and C# and I guess that's good. Unity is not accessible though, otherwise people would probably use it... The only people who I know who code their audiogames in Unity are sighted people... If we had a language as powerful as Unity without the accessibility problems, we could have some really good games out there already."

Our participants have shown they are involved in the creation of game elements through voice acting and sound recording. Moreover, at least one of our participants is well acquainted with the development tools used for the creation of audio-games and the limitations of mainstream game development platforms.

DISCUSSION

Our qualitative analysis of these interviews with expert GVI has identified two key relationships between the gamers and the games they play: relationships with the information being presented, and relationships of control over the game world. These relationships occur both when the gamer is playing—or using—a game and when the gamer is engaged in activities of creation.

This analysis led us to develop the GIC (Gamer Information-Control) framework. The focus of the framework is the key relationships that allow GVI to access games, where the presence or absence of these relationships inherently enables or prevents GVIs' access to games. Relationships with information are supported by representations of space and of real-world objects, while relationships with elements of control are mediated through internal, in-game elements, such as text commands, and external elements such as screen-reading software.

Relationships with information

Digital games convey navigational information for PVI through representations of the space and representations of objects from the physical world. These use metaphors from the physical world to communicate the affordances of the space

¹HRTF: head-related transfer function; that is, a function describing how sound reaches the left and right ear at slightly different time intervals.

and the actions available to the player character within the game space.

Conveying spatial information

Participants' visual impairment affects their relationship with physical space. As noted earlier, Juan summarised the perception of 3D space by most GVI in contrast to that of sighted players: *"we don't think that way, most of us"*. This aligns with the findings of Spiel et al. [75], Thinus and Gautnet [82], and Cattaneo et al. [24], who observed that PVI understand space differently than sighted players. Therefore, it is important for designers to consider how to best convey in-game spatial information.

Previous research has explored the relationship between space and sound in the context of embodied interactions [7, 89]. Our participants believe that combining binaural sound with head-tracking technology would result in an embodied interaction that would improve accessibility in digital games. Participants cited the *SeeMonkey* device as a promising technology for tracking the position of a player's head during the playing session, thus conveying information about space through a direct mapping of the physical and the virtual. Game designers may try embodied approaches to convey spatial information to GVI. This would improve the relationship between players and spatial information by more tightly coupling the two together, providing new signifiers to communicate positional information to all players (GVI or sighted).

Spatial information can be conveyed through other sensory inputs such as tactile or haptic [22, 64]. One of our participants noted the lack of additional sensory information. According to CJ, in digital games *"you don't have smell, or airflow, or anything like that"*. CJ's comments show a desire for additional channels of information. In previous research, haptic feedback has been used to assist people with visual impairment with mobility tasks in the physical world [3, 4, 17]. More recently, physical canes with haptic feedback to navigate virtual spaces have been designed [95], and cross disciplinary efforts have started exploring the use of scents to convey information [83]. There is an opportunity for game design to reduce overload on the auditory channel by considering other sensual input, such as haptic or olfactory feedback [15, 48, 51, 61]. This extended sensory engagement could enhance the player's sense of presence within the game.

Text is used to convey information to GVI, particularly in MUDs, where all the actions in the game are afforded through text commands. Our use of thematic analysis to "give voice to experience and meanings of the world, as reported in the data" [20], identified the importance and relevance of text-based interfaces for GVI. Carlos's opinion that text is a viable tool to convey spatial information that enables players to create a mental map of the game world to facilitate exploration, reflects this theme. While previous research on MUDs has focused on the types of players that engage with these games [11, 40] and the use of algorithms to automatically generate game layouts [39, 63], future research could explore the relationship between the use of spoken text and understanding of spatial information.

Marcela observed that so-called 3D audiogames really only allow for movement in four directions —up, down, left, and right. This restriction further constrains the relationship between GVI and in-game space. Works such as that of Andrade et al. [5] have explored the design of 3D virtual environments that give PVI freedom of movement and employ novel interaction metaphors such as echolocation to convey spatial information.

Conveying information through objects

Gaming is a deeply embodied experience in which the gamer is immersed in the game-world through the embodiment of a character [26,46,47]. GVI have even argued for the creation of sound-based character avatars [6]. This further justifies the use of extended sensory engagement to build a sense of embodiment and immersion in the game.

Just as the gamers themselves are embodied in-game through characters or avatars, objects and navigational tools may similarly be embodied, carrying and conveying metaphors and affordances from the physical world. Our participants described virtual representations of navigational tool objects such as radars or white canes. Other tools and objects such as footsteps and the echoes that result when those interact with walls are used in-game to convey information about the space. In the literature, radar and sonar-like systems have been used to indicate proximity to an object or person, for example, beeping more rapidly as the player walks towards a building [65]. These are examples of sound-based metaphors constructed around auditory icons that may be easier for PVI to associate with real-world phenomena than earcons [16,31,35].

Several of our participants use echolocation in the physical world, and one expressed an interest in using echolocation within the game environment as a further tool for exploring space. While previous research has established the usefulness of echolocation to identify size and materials of objects, and whether collisions are imminent in the physical world [27,45,50,54,78,80], and exploratory research has identified echolocation as a potential metaphor to convey spatial information in digital games [5,91], future research and game design could explore in depth the usefulness of echolocation as a metaphor to convey spatial information.

Voice is a non-physical element that is used to convey information. The spoken word is considered easier to process than earcons or auditory icons for conveying information [16,70]. However, voice seems to be missing from the gaming experience of GVI. While the use of voice interactions in digital games has risen and fallen "in seven distinct phases in response to new platforms and enabling technologies" [1], none of our participants mentioned voice as a means for interacting with digital games, although Alberto does refer to the use of voice to communicate with other players through external software. Allison et al. [1] discuss the difficulties currently associated with voice recognition and interactions, which are frequently due to the limitations of available technology. This is in line with the findings of Sánchez, et al. [69], who assessed interaction trends in multimodal videogames for the cognition of people who are blind and found that only two out of twenty-five games assessed provided support for voice-driven interac-

tions. Game designers may integrate design patterns for voice interactions in order to improve how information is conveyed to GVI [2].

Relationship with elements of control

Control is obtained through internal and external elements. Screen readers are a prime example of external control provided to GVI, while the use of text commands and other interfaces enables internal control of a game.

External control

Participants expressed the need to be in control of the gaming experience, with CJ commenting "*If [a game] is going to lag or crash all the time on my system, that's going to be a problem*", Carlos explaining how a particular screen reader "steals" the control of the keyboard and prevents gamers from playing certain games while the screen reader is on, and Alberto saying that he liked "*to have the screen reader on at all times*". CJ, Carlos and Alberto's comments coincide with findings in the literature examining access to websites by screen-reader users [52,92]. With screen readers being the main tool for PVI to work with computers [87], their desire to have the screen reader always on and not experience crashes is understandable. This study demonstrates how the GVI relationship to game interface controls differs from that of sighted players. Specifically, GVI control of screen readers should be privileged over other elements of control, because without this relationship, the GVI's gaming experience cannot start. Existing research has explored how screen-reader users recover from errors and crashes on the web [52,86]. Handling of game crashes and compatibility with screen-reading software must be considered carefully by game designers creating games for PVI.

Internal control

A prominent feature of internal control is enabling interactions between gamers and the in-game character. All the gamers that we interviewed mediated these interactions using the keyboard. Juan, however, mentioned that certain games let him use the mouse to control the rotation of the character. This demonstrates that internal control of in-game elements is enacted through peripherals that are familiar to GVI, as keyboard and mouse are standard input devices that PVI use to interact with computers [69,87]. Although some researchers have adapted mainstream console controllers for the use of GVI in experimental settings [25,79,89], the potential for these mainstream controllers to enrich GVI's gaming experience remains unexplored.

Control as a relationship goes beyond mediating interactions with in-game elements [87]. By internal control, we refer to the overall control gamers have over the gaming experience. Although all of our participants engaged with audiogames, some felt that MUDs offer more overall control over the gaming experience. As Carlos puts it, "*you can imagine what the world feels and looks and sounds like*". By not relying on elements outside the control of GVI such as earcons, MUDs may deliver a deeper relationship to some GVI, as the gamers can imagine the entire world game. However, the use of text as a device to control in-game interactions may alienate other gamers, such as Marcela, who doesn't like "*dealing with the MUD client... because there's a lot of typing*". Care should be

taken on how to integrate direct mechanisms of control such as text commands in a way that is appealing to GVI.

Gamers as players and creators

The relationships with information and elements of control described above occur when the gamer is partaking in the gaming experience —while they are playing *or using*, their games. However, our participants have been involved in the creation of voice pieces for audiogames to convey in-game information, have explored how to record 3D spatialised sounds, and have tried tools such as *BGT* to create their own games: players are becoming co-creators [62]. These experiences reflect the creating relationships that need to be supported in order to enhance the gaming experience of GVI and that are routinely available to sighted players [9, 66].

Carlos reflected on the tools used for the creation of audio-games, concluding that "*If we had a language as powerful as Unity without the accessibility problems, we could have some really good games out there already.*" There is at least one attempt that we are aware of to provide PVI the ability to create their own games, in the work of Stadler and Hlavacs [76]. Works like these enable an enhanced gaming experience, where gamers' lived experiences with disability is seen as a source of strength rather than as something that needs to be normalised [58, 67], and they are given means to explore different creative outlets. While our participants expressed their views on co-creating games, their views on ownership and creative processes have not been explored.

FURTHER WORK

This paper has identified a number of opportunities to further explore the use and creation of digital games by PVI. We have described the use of metaphors to represent space and information within the game and to signify in-game affordances. To date, no work has focused on the interactions between PVI and game controllers. There is an opportunity to explore how PVI appropriate and customise game controllers as enablers of in-game control. Additionally, no work has to date focused exclusively on the experience of PVI as game designers.

We identify extended sensory stimuli as having the potential to convey additional information. The inclusion of these additional stimuli has potential to reduce load on the auditory channel and extend the player's sense of presence, immersion and embodiment within the game.

Although this paper examines key relationships, our framework focuses on the experience of individual GVIs. Research has yet to explicitly consider the relationships between GVI and other players, whether GVI or sighted, and the ways in which the combination of their abilities and unique skillsets can be exploited to create novel gaming experiences and interactions.

CONCLUSIONS

In this paper, we have explored the understanding of the gaming experience of Gamers with Visual Impairment (GVI) focusing on the key relationships that enable GVI to interact with digital games. The relationship between GVI and information about the state of the game world is conveyed through

representations of space and representations of digital objects. The relationship between GVI and elements of control is mediated through internal game elements such as text, or external elements such as screen-reading software. Finally, these relationships with information and control elements occur both when the gamers are playing, or using, the games, and when they engage in creation activities.

The framework presented in this paper has provided a way of thinking about accessibility in digital games for PVI. We aim to encourage the design of games and game creation tools that are more accessible through the consideration of the elements outlined in our framework. This, in turn, will increase the capacity for people with different physical capabilities to fully engage with the gaming experience.

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