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Investigation in Visualization Accessibility Issues in Video Games

Under Review

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Abstract

Video games have developed as a culture and go beyond the form of entertainment such as social connection, education, and medical purposes. Due to its popularity and versatile nature, serving broader audiences with varying abilities in video games has also been a focus of research and practice. Many features and contents in video games, such as high contrast graphics and audio assistants, have been implemented to improve gaming experiences for people with low vision. However, there has been no research on how people with visual impairments interact with "data representations" in games, which communicate the essence of the quantitative perspectives of gaming. In this work, we review accessibility guidelines in video games that can be applied to visualization. We present a case study where we evaluate the real-world visualizations in video games with the guidelines. We report some cases in that visualizations do not follow the guideline to highlight the gap between the guidelines and the practice. To better understand the experience of people with visual impairments, we surveyed 25 visually impaired games and asked about their experience with visualization in video games. Lastly, we provide design implications for visualization in video games derive form our analysis and the survey results to inform future designs of accessible visualization.

CCS Concepts

• ***Human-centered computing*** → ***Empirical studies in visualization; Empirical studies in accessibility;***

1. Introduction

Video games have gone beyond just entertainment over the past decades. They are now considered cultural and educational mediums. For example, video games have been employed in areas like education [Squ03, K*08] and medical science [Cer10]. Due to their increasing popularity, with a total 3.24 billion gamers in the world [Cle], video games have a significant impact on the world that we are living in [DG18].

Among all the video game players, 23 million are blind or visually impaired. However, video games have been notoriously inaccessible to people with visual impairments for various reasons (e.g., [MOA*08, AGH*20]). Accessibility of data visualization can not be an exception. While data visualization in games has a long history of being used as a medium to convey data to players [Zam08], there are no clear guidelines or research that prescribes how visualization should be designed for people with visual impairments in the context of video games.

To better understand visualization accessibility issues in video games, we analyzed accessibility guidelines related to data visualizations for low vision individuals. We showcase how data representations used in the real game do and do not meet the suggested guidelines. We survey 25 video game players who have low vision to further understand their experience with visualizations in video games and identify the accessibility issues and corresponding solutions for data visualizations.

The accessibility guidelines that can be applicable to visualizations are ranged from font size to color contrasts. Using these guidelines, we found that visualizations that appeared in popular games do not fully meet the accessibility guidelines. The responses from the survey participants also indicated that there are huge opportunities to improve visualization accessibility in video games. Participants suggested possible solutions for various issues; for example, in addition to every element being legible for them, the placement of the visualization matters in their experience as they are often placed at the corner of the screen. The suggested solution includes the dynamic placement of the visualizations within their field of view.

We made several contributions. First, we applied the accessibility guidelines to a sampled set of visualizations that appear in real-world games. This analysis provides a crude sense of how accessibility guidelines are being met in the wild. Second, we report the findings from a survey from 25 low vision gamers, providing insights into their perception of various visualizations in video games and possible solutions to the accessibility issues. Lastly, we conclude by suggesting a set of design implications derived from prior guidelines, as well as the finding from our analysis and the survey.

2. Related Work

2.1. Roles of Visualizations in Video Games

Game data visualization research can be traced back to 2008, where Zammitto [Zam08] was among the first to study the link between visualization and the visual data offered in games. They picked three game genres, First-Person Shooter (FPS), Real-Time Strategy (RTS), and Massively Multiplayer Online (MMO), and selected a few games from each of the genres. Their work finds evidence of the usage of data visualizations in these games. In FPS games, quantitative display of data is often used for health, ammunition, and armor. Color coding is used for the change of status, the silhouette is used to indicate the required actions for players (for fast recognition), and way-finding to navigate the game world. For RTS games, pre-attentive processing is frequently used, as well as edge enhancement and use of levels of detail.

Building on the foundation of Zammitto's work, Bowman et al. [BEJ12] takes a step toward developing a theoretical framework and technique for game visualization. They define the design framework and encode common game visualizations into a visualization taxonomy. Their works focus on improving visualizations so that existing players can enhance their skills, but they did not consider players who require accessible visualization in games.

2.2. Accessibility Considerations in Video Games

A video game is electronic software that requires user inputs and provides feedback like video, audio, and even tactility. With the growing availability and market penetration in the 21st century, video games are currently being used for entertainment and educational purposes. As a result, video games can change people's perceptions and beliefs about the world and their own environment. However, there are still huge accessibility issues in game designs, hindering broader audiences from playing games.

Simultaneously, academics, the game development industry, and player communities have been worked for accessibility that may benefit the underrepresented users. More Than Just a Game: Accessibility in Computer Games [MOA*08] proposes that game interfaces principles should be added to the standard HCI practice. For example, the game accessibility guidelines can serve as a basis to work with in game industries, and code boxes and documentation that could provide resources and references for future game developers.

Gaming communities have been contributing forces to this trend. Founded in 2003, The IGDA Game Accessibility Special Interest Group (IGDA-GASIG) has volunteers aiding the game industry to make more accessible games for people with varying abilities. They released a white paper [whi] that included their research data, principles, and survey results from players and developers. Game accessibility guidelines [gui] were also designed for developers' reference. They include various categories of instructions for different impairments.

Accessibility in video games has been a focus of research by many studies. "Game Accessibility: a Survey" [YFH11] that looks into accessible games and the strategies used in them. For example, this work proposes visuals in games for visually impaired players may be replaced with audio and haptic or enhanced to support low-vision players. They also consider accessibility for motor-impaired players, hearing-impaired players, and cognitively impaired players. Their work also highlights the lack of accessibility supports in many games.

Prior work has also surveyed the status of video games accessibility. "Accessibility in video games: a Systematic Review" [AGH*20] did a Systematic Mapping Study and analyzed 45 related studies. The study showed that video games being developed today are not truly accessible, and the solutions being proposed to increase accessibility are not enough. It also shows that the pursuit of universal accessibility is hard and not profitable. As a result, they propose to create an integrated software engineering methodology in game development that considers accessibility guidelines, techniques, strategies, human factors, etc.

Aside from analyzing techniques used for game accessibility, there are also empirical studies that gather opinions from players and developers from game industries. An Empirical Study of Issues and Barriers to Mainstream Video Game Accessibility [PK13] address a question related to the reason behind the current inaccessibility nature of video games. They found the barriers are closed related to the preference from game developers and the game technology support.

Specifically for low vision individuals, "Exploring the Experiences of Streamers with Visual Impairments" [JSP*21] conducted a qualitative interview with visually impaired streamers to explore the barriers and challenges they face.

In our understanding, none of the prior work focuses on the intersection between visualizations and accessibility in video games. We envision the research related to the accessibility of visualization in video games are particularly important because of the following reasons. First, visualizations carry important quantitative information that impacts better gameplay. To equalize the gaming experience between people with visual impairments and sighted individuals, accessibility consideration toward visualizations is imperative. Second, we believe that the general accessibility considerations of graphics cannot be fully transferred, which improvement efforts are heavily focused on.

3. Evaluating Game Visualization with Accessibility Guidelines

To understand the current standard and expectation of accessibility in video games, we analyze the existing accessibility guidelines related to data visualization. Then to understand the extend to which visualization designs in video games followed the guidelines, we collect several examples in the wild. We evaluate each visualization with an emphasis on various aspects of a visualization based on the guidelines.

3.1. Guideline Analysis

Guidelines were collected through Google search using pertinent keywords such as video games accessibility and accessibility guidelines, resulting in 6 websites. We excluded guidelines that were generated by citing other guidelines, guidelines that focus on

motion or hearing disabilities, or guidelines that are too general without detailed rules. Game Accessibility Guidelines [gui] was left after filtering with the above criteria.

Among the set of guidelines included in the Game Accessibility Guidelines website [gui], we selected items that are relevant to data visualizations for low vision individuals. To assess relevance, we first filtered the items based on whether they are related to low-vision individuals. Then, we further reflected on all visual components in visualizations, including marks, channels, peripheral information (e.g., legend, labels) to assess whether the guideline can be applied to any of the visual components. This process resulted in 8 items out of around 150 items on the website.

Some guidelines should be applied at the game-level (e.g., overall game setting, Table 1). For example, customization options can be provided via game setting menu, instead of an individual scene. Some guidelines should be applied at the scene-level.

The selected guidelines are:

Game-level guidelines

- **Font Size Customization:** Allow the font size to be adjusted.
- **Contrast Customization:** Provide an option to adjust contrast.
- **Flexible Interactivity:** Ensure interactive elements / virtual controls are large and well spaced, particularly on small screens and touch screens.
- **Interaction Customization:** Provide an option to turn off / hide background animation.

Scene-level guidelines

- **Colorblind Friendly:** Ensure no essential information is conveyed by color alone.
- **Font Visibility:** Use an easily readable default font size.
- **High Contrast:** Provide high contrast between text/UI and background.
- **Re-sizable:** Allow interfaces to be resized.

3.2. Case Study

To evaluate current practices, we chose six scenes from various video games. We chose all the stimuli from 6 trending games that have influences and leading sales in recent years [vgc]. In choosing these stimuli, we considered the diversity of chart types and visual elements to observe a range of accessibility considerations.

The selected scenes and visualization components that we focus on are the following:

- **A simple bar chart (V1)** representing health points from *Mortal Kombat 11*, shown in Fig. 1a. In this scene, we focus on the bar charts, which are the most common chart type [DK09].
- **Dendrogram (V2)** representing a development of civics from *Civilization VI*, shown in Fig. 1b. In this scene, we focus on understanding hierarchical information.
- **A dot plot with color encoding (V3)** representing health points from *Ghost of Tsushima*, shown in Fig. 1c. In this scene, we focus on the color-coding aspects of the visualization.
- **Contour visualization with size and opacity encoding (V4)** representing the distance of enemies from *The Last of Us II*, shown in Fig. 1d. In this scene, we focus on a different set of encodings, namely size and opacity.
- **Summarized map visualization (V5)** designed to be pre-attentive from *FIFA 21*, shown in Fig. 1e. In this scene, we focus on how each position of dots are readily available to readers.
- **Numerical labels (V6)** from *Fortnite*, shown in Fig. 1f. In this scene, we focus on the numerical labels shown alongside the bar chart and labels that are floated around the scene.

Table 1 summarizes how the six scenes conform to the guidelines.

V1 Simple bar chart (Fig. 1a) does not offer any means to read the value of health point other than reading how long a yellow bar is. The bar also changes color based on the status of the character health (red indicates low health). This violates the Colorblind Friendly guideline that the designers should ensure no essential information is conveyed by a color alone. In this example, the bar is displayed with bright yellow (rgba(255,252,85,255)) ensuring high contrast between the bar and the background (contrast ratio: 12.75:1). However, in order to glance at the percentage of health left, users must compare the current length of the yellow bar to the full length of initial bar which is represented in black with a small and faint yellow border. This visualization component has much lower contrast, which may impair the ability of people with visual disabilities to accurately access the percentage of health left.

V2 Dendragram (Fig. 1b) is colorblind friendly. Although the development of civics of the player's country is represented by color-coded badge icons in the dendogram, the icons' shapes can also be used to differentiate between the various components of the game. As a result, there is no critical information that is displayed through color alone. However, due to color coding, the design of the badge have low contrast. For example the yellow diamonds can not be well noticeable against the yellow background of the badge. Regarding hierarchical visualizations, they display hierarchical data using nested structures [KHA10]. In the case of *Civilization VI*, analyzed in our study, players need to interact with the hierarchical visualization, selecting nodes in the tree to take action. However, the game does not provide size, spacing, or layout adjustment features. It also does not provide a way to customize the font size and contrast.

V3 A dot plot with color encoding (Fig. 1c) does not meet accessibility guidelines, since it uses the salience of colors to match the importance of the information being conveyed [Won11]. This accessibility issue was most visible in *Ghost of Tsushima* where color changes from transparent to red with increasing intensity in the dot plot highlighted in Fig. 1c indicates the decrease of health points of the character. Furthermore, the game does not allow for the adjustment of colors, contrast or the size of the dot plot, seriously hindering the accessibility to critical information in the gameplay dynamics.

V4 Contour visualization with size and opacity encoding (Fig. 1d) uses the high contrast silhouettes to represent or highlight the distance between the user and the enemies. Silhouette size can be proportional to the distance of objects or opponents in the game, encoding additional information in an accessible format. Games like *Battlefield V*(Fig. 7) and *The Last of Us II* (Fig. 1d) adopts this strategy to highlight various objects. This is in contrast to games such as *Ghost of Tsushima* (Fig. 1c) and Fortnight (Fig. 1f). As a

(a) V1: Bar chart in Mortal Kombat 11. The health point of each character is encoded in the health bar at top of the UI.

(b) V2: Dendrogram in Civilization VI. The development of civics of a player's country is encoded in dendrogram.

(c) V3: Color coded dot plots in Ghost of Tsushima. The health point is represented by colors on the screen.

(d) V4: Contour visualization (Silhouette) in The Last of Us II. The distance of enemies is encoded as the size and the opacity of the contours.

(e) V5: Summarized map visualization in in FIFA 21. The different shapes in the mini-map symbolize players in different teams.

(f) V6: Numerical labels in Fortnite. The health, damage, ammunition quantity, and resources quantities are represented in numerical form.

Figure 1: The selected scenes and visualization components considered in our study.

result, the location of enemies, rewards or other objects may be difficult to be perceived by people with visual disabilities. *The Last of Us II* (Fig. 1d) not only provides silhouettes, but it also supports the adjustment of contrast, which makes silhouette visualization more accessible. Though there are no options to customize the size, color or other silhouette specific characteristics.

V5 Summarized map visualizations (Fig. 1e) are often used in games to summarize and communicate the location of objects and opponents in the game environment. Such map visualizations may depict a global view as in the case of *FIFA 21*, or partial maps relative to the main character location as in the case of first person shooter games. The different components of the game like rewards, opponents, environment layout, or the main character itself, are represented using distinct icons or colors. As a result, map visualizations are often not colorblind-friendly. Despite relying on color, *FIFA 21* (Fig. 1e) also uses different marks (circles and triangles) to distinguish between home vs away team players. Furthermore, it supports contrast customization which also improves the accessi-

	Game-level guidelines					Scene-level guidelines			
Game	Font Customization	Contrast Customization	Interaction Customization	Flexible Interactivity	Visualization Component	Colorblind Friendly	Font Visibility	High Contrast	Re-sizable
V1 – Mortal Kombat 11	✗	✓	✓	✗	V1 – Bar Chart	✗	✓	✓(12.75:1)	✗
V2 – Civilization VI	✓	✗	✓	✗	V2 – Dendrogram	✓	✗	✗(2.57:1)	✗
V3 – Ghost of Tsushima	✓	✓	N/A	✓	V3 – Dot Plot	✗	N/A	✗(1.66:1)	✓
V4 – The Last of Us II	✓	✓	N/A	✓	V4 – Contours	✓	N/A	✓(14.58:1)	✗
V5 – FIFA 21	✗	✓	✓	✓	V5 – Map Vis	✓	✓	✗(1.53:1)	✓
V6 – Fortnite	✓	✓	✗	✗	V6 – Numerical Labels	✓	✗	✗(2.23:1)	✗

Table 1: A summary of evaluations of each game based on the game-level and scene-level guidelines.

bility of the map visualization. However, it does not allow users to adjust the size of the map or the size of the various components in the map.

V6 Numerical labels (Fig. 1f) are often used to communicate quantitative information about game status. It can be used to complement visualizations like bar charts (bottom left) displaying the exact value represented in the plots. It can also be used to communicate which weapon is currently being used, ammunition or information about other resources (bottom right). Explicitly communicating critical information through text improves accessibility, as users are no longer required to interpret less accessible or abstract visualizations. The use of numerical and textual data was also well applied on games like FIFA 21 (Fig. 1e) displaying the game score, time, and current selected player, but only sparingly used in games like *Ghost of Tsushima* (Fig. 1c), Mortal Combat (Fig. 1a) or The Last of Us II (Fig. 1d). Despite the use of numerical and text data in Fortnite, font visibility was overall poor using default settings (due to both small fonts and low contrast). However, Fortnite allows players to adjust these components in the game settings.

3.3. Summary

From the above analysis, not every games and elements in games meet the guidelines. This is aligned with other prior work that concern general accessibility in video games.

The available guidelines suggest that data visualizations in video games are less accessible than the simple display of data (i.e., numerical lables in our analysis). However, game developers need to strike a balance between easy to glance, fast to decode, accessible visualizations for summary information, and explicit textual data for displaying critical data. Therefore, further research on where the balance is will be needed to maximize the gaming experience for people with low vision.

4. Survey: Investigation on Accessibility Issues

To further understand how accessibility issues manifest in the wild, we surveyed low-vision gamers. We sought to observe 1) the experience of gamers with data visualization in video games, 2) how accessible data visualization components are to gamers.

4.1. Participants

To recruit participants, we disseminate our survey links in three ways. We sent an email soliciting the survey via a mailing list hosting people with visual impairments. We also posted the invitation in the "blind" group of Reddit under the agreement of moderators. Lastly, we invited visually impaired gaming YouTubers and streamers on YouTube and Twitch. Our recruiting criteria filtered for participants that are 1) 18 years old or older, 2) legally blind, and 3) experienced with video games. After filtering out respondents that do not meet the criteria, we left with 25 valid responses. The survey was designed to last 30 minutes. We compensated all participants with a $10 gift card.

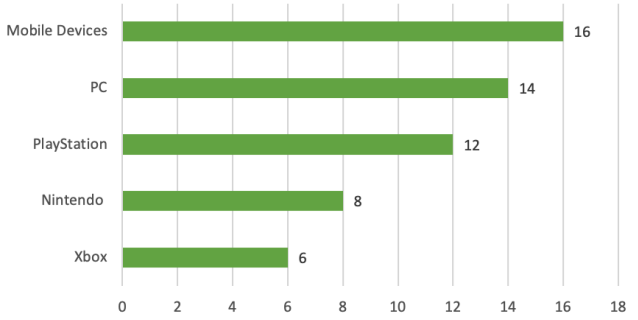

Figure 2: Number of participants who play on different gaming platforms. We allowed participants to choose multiple options.

Participants' demographics are shown in table 2. Among the 25 participants, 15 identified themselves as male, and 10 were female. The average age was 25.6 (SD: 7.1). While all participants were legally blind, they all had low vision. Most of them have visual acuity of around 20/200, with two people having acuity of 20/400.

Participants indicated that they had experience with gaming platforms. Mobile devices, PC, and PlayStation were most popular (Fig. 2). Participants had gaming experience with action, adventure, sports, fighting, MOBA, and puzzle genre of games. Sports, action, and adventure games were the most popular genres, being familiar to 72%, 68%, and 52% of the participants, respectively.

4.2. Method

The survey starts by asking demographic questions, including their gender, age, visual condition, and gaming experience. Then, we presented the six game scenes evaluated in Section 3.2 (i.e., Fig. 1a,1b,1c,1d,1e, and 1f) with a few extra similar visualizations to provide additional context.

The six visualization components that we wish participants to recall and reflect upon were introduced as follows.

Pid	Age	G.	VA	VF	LS	Gaming Platform	Gaming Types
P1	25	M	20/200	N/A	Y	PlayStation;XBox;PC	Arcade, Action, Sports
P2	22	M	20/200	N/A	Y	PlayStation;PC	Action, Arcade, Sports
P3	54	M	20/200	12	Y	PC;Mobile Devices	card games, puzzle, Adventure
P4	30	M	20/200	N/A	Y	PlayStation;XBox; Nintendo;PC;Mobile	Simulation, Sports
P5	25	F	20/200	N/A	Y	PlayStation;Mobile	Action, Adventures
P6	24	M	20/70	20	Y	PlayStation;PC	Action
P7	22	M	20/200	20	Y	PC;Mobile Devices	Sports, Adventure, Action
P8	22	F	20/160	20	Y	XBox;Nintendo	Action, Sports, Adventure
P9	25	M	20/200	20	Y	PlayStation;Mobile	Fighting, Sports
P10	24	F	20/400	20	Y	XBox;Nintendo	Action, Adventure
P11	20	M	20/200	20	Y	PlayStation;PC	Adventure, Sports
P12	22	M	20/400	20	Y	Nintendo;PC;Mobile	Action, Sports, Adventure
P13	24	F	20/400	20	Y	PC;Mobile Devices	Action, Sports
P14	25	F	20/400	20	Y	Mobile Devices	Action, Sports
P15	20	F	20/200	20	Y	Mobile Devices	Action, Adventure, Sports
P16	21	M	20/200	20	Y	PlayStation;Mobile	Adventure, Sports
P17	24	F	20/70	20	Y	Nintendo;PC;Mobile	Puzzle, MOBA, Adventure
P18	18	F	20/200	20	Y	PC;Mobile Devices	Action, Adventure, Sports
P19	28	M	20/200	20	Y	PlayStation;Nintendo	Sports, Action
P20	27	M	20/200	20	Y	PlayStation;XBox;Mobile	Action, Sports
P21	26	M	20/200	20	Y	PlayStation;XBox;Nintendo	Sports, Action
P22	20	M	20/400	20	Y	PlayStation;PC	Action, Sports
P23	25	M	20/400	20	Y	PC;Mobile Devices	Action, Sports
P24	26	M	20/200	20	Y	PC;Mobile Devices	Action, Sports, Adventure
P25	18	F	20/200	20	Y	Mobile Devices	Sports, Adventure

Table 2: Demographics of participants: Pid=Participant ID. G.=Gender (M=Male; F=Female). VA=visual acuity. VF=Visual Field. LS=light sensitive

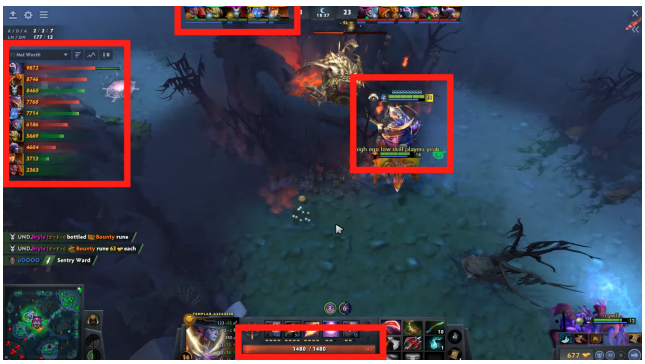

Figure 3: Bar charts used in Dota 2. The quantity of possessions, health and energy are represented by the length of bars.

- **Simple bar chart (V1)**: A simple bar chart is a visualization that presents single quantitative information using the length or height of the bars. Several bar charts are highlighted by red boxes. They are used to represent certain values in the game, such as the amount of health, skills, or ammunition in figure 3.
- **Dendrogram (V2)**: Dendrograms are visualizations for hierarchical data. For example, in 1b, you need one law to unlock some policies, and from these policies, more sub-policies are branched. In 5, minor skills are subdivided from more general skills.
- **A dot plot with color encoding (V3)**: Color-coded information is often used to indicate the status change in games. For example, in figure 1c, the health is dangerously low, and the environment changes from the regular color to red.
- **Contour visualization with size and opacity encoding (V4)**: Silhouette is used to show important information regarding the distances in many games. In both figures 1d and 7, close enemies are shown with clear, big silhouettes, and far enemies are in vague and small contour.
- **Summarized map visualization (V5)**: This example shows a map visualization that summarized the entire field with the location of players. It gives you very quick overall information related to the scenery.
- **Numerical labels (V6)**: The numerical labels are often used for conveying exact data values. Several values are highlighted by red boxes in figure 1a and 3.

In each category, we asked participants three questions. The first question was related to their experience. For example, for the bar chart example, we asked "Please take some time to recall when you encountered bar charts in games. How is your experience with them? How easy or hard to see and understand them compared to

Figure 4: Numerical labels in League of Legends: quantities of resource are in their numerical form.

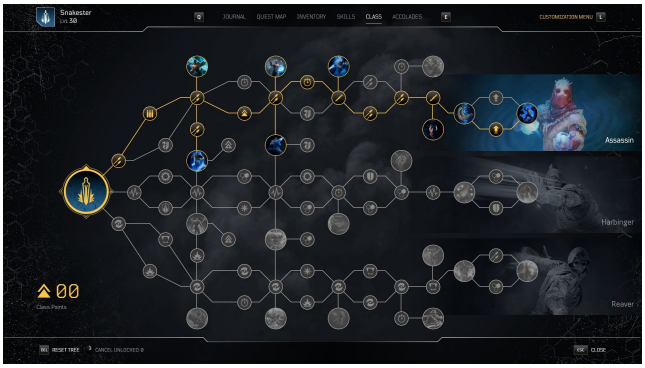

Figure 5: Dendrogram in Outriders: detailed skills are subdivided from general skills.

other elements in games?." The second question inquired about the usefulness and informativeness of the visualizations: "Do you think they convey the information you need in the game?." The last question captured the accessibility aspect of each aspect: "Do you think bar charts presented in games take accessibility into account? "

4.3. Analysis & Findings

We aggregated all responses, and two researchers reviewed them all. The two researchers iteratively categorized the responses based on the stimuli we showed and emerging themes.

4.3.1. V1: Simple Bar Charts

Most participants have a positive experience with bar charts. Several participants mentioned that bar charts tend to be accessible to them, considering the fact that these charts only need to support low-vision individuals to 1) locate the chart itself and 2) read simple information (single value) out of them. As P8 stated, "All of the games I've played has a visible bar chart." P5 echoed "They were visible enough for me."

Some participants had suggestions for making bar charts more accessible in video games. Mainly they emphasized two aspects: the location of the bar charts and the colors used in bar charts. For example, P17 mentioned, "Bar charts are actually quite helpful, but their placement must be easily seen. I always refer to them for my and my enemy's health bar. Without it, I am pretty much lost and cannot play the game as intended." P19 also noted that "They are really good in conveying information, especially if I can easily spot where it is. Bar charts are typically better than just numbers since it is easily spotted."

A few participants argue that bar charts should be placed in the middle of the screen to support people with a limited field of view. In most games, the information presented with bar charts are often placed at the corners of the screen (e.g., Fig. 1a, 1f, 6). This placement can distract the players, as they have to move their head to read the chart. It can also make the chart go unnoticed for someone who has a limited field of view. For example, P17 shared "Bar charts are definitely more accessible than numbers. I would want them to be more prominent in a way that it is in the middle of the screen or at the player's head in Fortnite since my vision is limited. Also, make the bar charts bigger so I can see them immediately." Some allude that the dynamic positioning of these charts might be more useful. As P3 stated "Bar charts are great, especially the ones over the onscreen characters. I'd improve them by moving them from the corners and making them all over the characters."

Bar chart visualizations should also follow the high contrast principles. As P13 shared "They would improve by using brighter colors." P23 also echoed the importance of colors in visualizations, "About improving presentation to suit my needs, I'd advice video game programmers to use brighter or secondary colors in bar charts."

4.3.2. V2: Dendrograms

Most participants indicated that hierarchical visualizations could be very helpful in conveying information. For example, P25 mentioned "they are very handy and informative." P11 also echoed the usefulness of the visualization "Tree visualizations are great. They don't hinder gameplay for me at all."

Surprisingly, this type of visualization has received the most positive comments. Some mentioned that the *information* presented with this format is useful. For example, P15 shared, "They help me understand how my skills are evolving or how everything comes about." In terms of representations, participants mentioned that somehow it is very accessible. As P3 stated, "I don't know if they take accessibility into account but even if they didn't they're one of the more accessible features of a game for me." P4 also echoed "A graph like this is mostly helpful for me to understand the evolution of skills and the like. It is most especially helpful for story games too."

Also, some indicated that the *way* that is presented is often useful, often being placed in a separate page (e.g., Fig. 1b and 5). As P2 stated, "They show prerequisites and descriptions and options relative to each other. They're much easier than putting the information on different screens and making the player toggle between them to compare them."

Some participants commented on the colors in this case as well. P4 "I just want the color scheme to be better that is not too flashy to the eyes but still have enough contrast for my blurry eyes."

Figure 6: Diablo 3 is a dark-themed game where every element is toned down.

Figure 7: Silhouette in Battlefield 5: the distance of enemies is represented by the size of contours.

4.3.3. V3: Dot Plots with Color Encoding, Color-Coding

Color encoding seems useful when done properly. Participants appreciated when color differences could quickly convey simple information. For example, P14 shared, “Color coding is very visible. They don’t hinder my gaming experience. As a matter of fact, I can’t help but love this feature.” P20 echoed the sentiment: “Color coding is very easy to see and notice in video games.” Some participants even mentioned that “color change” can convey information effectively. As P8 stated, “Whenever I see the color change from Green to Red, I need nobody to tell me that my character is about to get killed if I don’t do something about it and fast.”

However, some do not appreciate the use of colors in games entirely. As P17 shared “I believe this color coding is just for normal vision people to appreciate. Sometimes I do get dizzy after playing with this kind of setting.” P1 also echoed, “The color coding often does not take accessibility into account. I would probably want more contrast in colors for the games.” In fact, some games use very similar colors for most objects and scenes. For example, the *Dark Souls* and *Diablo*(Figure 6) series are dark-themed, featuring some scenes that are even hard to see for regular players. Participants indicated that these dark themes can be too dark to distinguish colors. As P3 shared “Dark games and games without much color contrast are harder for me to play. The first Diablo game is really bad at this - it all takes place in a dark, grey, underground location. P16 echoed the sentiment: “This [theme] is one area that needs improvement, having in mind that we’ve people that are color blind or visually impaired.”

Participants share their perspectives on how to improve color coding in games, expressing a desire for color/theme customization. Participants expressed that it can be helpful to select high-contrast colors or to let color-blind players choose their preferences of colors to be applied universally throughout the game beyond what is offered by default. As P3 stated, “Many games have an option screen where the player can customize the contrast. That helps. So does customizing the player’s character. But I’d really like a way to customize the enemy’s appearance so I can see them as easily as someone who isn’t visually impaired can.”

4.3.4. V4: Contour Visualization (Silhouettes) with Size and Opacity Encoding

Silhouettes also received positive reactions from participants. Since silhouettes often use white-toned colors, they often have high-contrast against dark backgrounds. For example, P7 mentioned that “Silhouettes are not hard to see in video games and they aid with the gaming experience.” P8 strongly echoed what others said: “As a matter of fact, silhouettes are one of the most easily noticed features in games.”

Only a few participants emphasized the negative side of the silhouettes where it overlays with other objects. “Yes, I do not quite see them in the games I play. I am not able to appreciate it. I feel like they are only glares which may hinder gameplay." as P17 stated. Some suggested that the threshold of opacity (mapped to the distance of enemies) should be adjusted to be visible. For example, P18 shared “in terms of improvement; they should consider using brighter colors for enemies in far distance.”

P3 suggested customization options for this type of visualizations “Brighter silhouettes like Battlefield (Fig. 7) help. The dim ones aren’t very helpful. An option for players to set the silhouette activation would be nice. I mean situations when I’m not mousing directly over an object, but I’m mousing close to it the silhouette lights up.”

4.3.5. V5: Summarized Map Visualization

Summarized map visualizations often display the overview of a scene. In sports games, they provide topological information regarding gaming elements. For example, P17 shared, “It gives me an edge, where people are placed and where to pass the ball or whatnot.” Some participants suggested they provide a “fast view” regarding what is going on. For example, P23 shared, "They are very fast in letting me know which of the players I am using." Often these visualizations are easy to locate, as P21 stated “They are not hard to see."

Some mentioned these representations are particularly useful in the context of sports games. As P17 stated, “This information is highly relevant for me to beat my opponents especially in FIFA and NBA 2k21”. P24 echoed “The need for these visualizations, especially in sports, cannot be over emphasized.”

Figure 8: While Mario Kart 8 Deluxe are widely played, it lacks essential visual elements accessibility supports many accessibility customization features.

A few participants proposed that the size and the shape of these overview-type information panels should be customized (P1, P3). According to our research, some games such as FIFA 21 started supporting this customization, but not many games support these features even though they are wildly played, such as Dirt 5 and Mario Kart 8 (Fig. 8).

Many participants highlighted the contrast between the map visualization and the background once again. For example, P17 shared, "Accessibility is taken into account, but I would just want it to have more contrast in terms of colors and one tone for each team only. For example, my team would be blue, and the other team would be red dots. This would help me see things clearly. If only it will also be a bit larger and somewhat placed near the center, this would be preferable."

Since these overview representations often appear at the bottom or the corner of the screen, some participants mentioned overlaying options. For example, P3 mentioned that "A transparent, overlaid map would be nice. In the examples you use in this survey, I wouldn't see the map items highlighted without diverting my vision from the main screen."

4.3.6. V6: Numerical Labels

Almost all participants stated that numerical labels floating around the screen or positioned next to charts are easy to see and convey information well in games. For example, P8 shared "They are not hard to see neither do they hinder me from playing games." P1 also stated that "They do a wonderful job conveying the intended information."

While many participants echoed the same sentiment, we observed a few comments about its accessibility. For example, P17 suggested that "It hinders me from playing the game, ... especially the ones in the monsters head are not needed. It just distracts me and hurts my eye due to the light flashing. My health bar is also enough without the need for the numbers."

5. Discussion

In our guideline analysis, the case study, and the survey, we observed that there are many unresolved issues around visualization accessibility in video games. For example, the contrast between visualization elements was constantly mentioned by participants. Furthermore, the remote locations where visualizations are often placed hinder participants' gaming experience. Based on the observations from the studies above, we derive design implications for visualizations in video games to inform game designers.

5.1. Design Implications

Participants often mentioned contrasts issues when examining all six stimuli. Although clear guidelines call for higher contrast, the analyzed games still have low contrast issues. Dark themes further exacerbate the issue. Designers should therefore offer a different theme based on the contrast level, in addition to customizable contrast ratios.

Some participants mentioned that there is not enough contrast between the chart itself and the background, or the contrast within the visualization element (e.g., two colors used in a chart). The guideline related to high contrast should be applied to every "item" in the game and to every "visualization component", such as axes, labels or legends.

Customization for Hue/Opacity Mapping We also observed the need for more detailed customizations in visualizations. For example, a few participants indicated that the lower value of the silhouette could be too faded (e.g., enemies are very far; therefore, the silhouette is almost transparent). We envision functionality where players could personalize visualization components such as the minimum or maximum opacity. In other words, the Just Noticeable Difference threshold can be different for different individuals based on their visual conditions. Offering personalized mapping based on those thresholds will greatly improve the visualization accessibility in games. We envision a quick test (inspired by many perceptual psychology studies in visualization community e.g., [Sza17]) to determine the threshold by asking participants whether two stimuli with varied hue/opacity are different or not. The stimuli can be gradually changed based on their responses to find an optimum for individual players.

Placement of Visualization Participants mentioned the placement of visualizations is critical for visualization accessibility. For example, the data representations are often presented at the edge of the screen. Thus, people who have a limited field of view need to move their eyes to see the chart, causing a distraction from the gameplay. We envision accessibility features that allow critical visualizations to be toggled on and off at the center of the screen or to allow players to enter their own field of view to dynamically place the essential visualizations within the visible radius.

Participants also mentioned that they need to locate the visualizations, which can sometimes be challenging. Animations can be helpful to highlight their location. For example, on the tutorial page, the chart could be placed in the middle and then animated to the corner to communicate the final location.

Rethink about Usefulness of Labels In our analysis, participants had no issues reading numerical or textual labels, as many

current games allow players to adjust font size. Since more and more games offer this feature, visualization designs can leverage this trend. While presenting all the necessary quantities through numerical labels can be obtrusive, the designers should not be hesitant to present numbers near the visualization elements if they convey essential information.

5.2. Limitations & Future Work

Our analysis and survey were conducted with a limited number of study stimuli and a limited number of games in the wild. However, this work paves the way to draw researchers' attention in visualization and accessibility communities and set up a study pipeline that can be replicated with a larger corpus of game stimulli. We envision that future work can expand the set of visualization components and expand the genre of games to evaluate their accessibility.

Accessibility efforts are often hard to capture the attention of designers. It would be great if visualization accessibility could leverage the existing accessibility standard. Future follow-up work should draw the parallels between visualization components and graphics elements used in video games in order to identify accessibility principles that can be directly applied, so as to maximize existing accessibility efforts.

More research should also be conducted to identify the components that can be adjusted at the game-level, such as font-size customization. Universal customizations that can be easily propagated throughout the game can offer the most efficient way to enhance accessibility. For example, we envision a feature "overview visualization size" allowing players to choose the location and the size overview visualizations. However, more thorough research should be conducted to identify the commonalities between visualization types and elements and provide a knob to adjust them all.

Our findings from the survey do not make any inferences based on participants' vision conditions. Identifying specific needs based on specific visual conditions is also an important direction of future work to provide more personalized solutions to visualization accessibility issues.

6. Conclusions & Future Works

As the industry of video games is evolving rapidly with accessibility support, we were motivated to identify the performance of data visualizations in video games in terms of their accessibility. We performed an analysis to understand the current state of visualization accessibility in video games using existing guidelines, and we surveyed 25 low-vision gamers to further understand their needs and preferences. We hope our work draws more attention to an important issue of visualization accessibility in major mediums of our society that people enjoy playing and learning from.

By adopting both research approaches, we identified four potential solutions that can improve the accessibility support of visualizations and an additional finding (i.e., the need for new guidelines) from comparing two research approaches.

References

[AGH*20] AGUADO-DELGADO J., GUTIÉRREZ-MARTÍNEZ J.-M., HILERA J. R., DE-MARCOS L., OTÓN S.: Accessibility in video games: A systematic review. *Universal Access in the Information Society 19*, 1 (Mar. 2020), 169–193. doi:10.1007/s10209-018-0628-2. 1, 2

[BEJ12] BOWMAN B., ELMQVIST N., JANKUN-KELLY T. J.: Toward Visualization for Games: Theory, Design Space, and Patterns. *IEEE Transactions on Visualization and Computer Graphics 18*, 11 (Nov. 2012), 1956–1968. doi:10.1109/TVCG.2012.77. 2

[Cer10] CERANOGLU T. A.: Video games in psychotherapy. *Review of General Psychology 14*, 2 (2010), 141–146. 1

[Cle] CLEMENT J.: Number of video gamers worldwide in 2021, by region. https://www.statista.com/statistics/293304/number-video-gamers/. Accessed: 2021-10-30. 1

[DG18] DANIEL M., GARRY C.: *Video games as culture: considering the role and importance of video games in contemporary society*. Routledge, 2018. 1

[DK09] DONNELLY R., KELLEY W. M.: *The Humongous Book of Statistics Problems: Nearly 900 Statistics Problems with Comprehensive Solutions for All the Major Topics of Statistics*. Penguin, 2009. 3

[gui] Vision set of game accessibility guidelines. http://gameaccessibilityguidelines.com/full-list/. Accessed: 2021-09-30. 2, 3

[JSP*21] JUN J., SEO W., PARK J., PARK S., JUNG H.: Exploring the experiences of streamers with visual impairments. *Proceedings of the ACM on Human-Computer Interaction 5*, CSCW2 (2021), 1–23. 2

[K*08] KEBRITCHI M., ET AL.: Examining the pedagogical foundations of modern educational computer games. *Computers & Education 51*, 4 (2008), 1729–1743. 1

[KHA10] KONG N., HEER J., AGRAWALA M.: Perceptual guidelines for creating rectangular treemaps. *IEEE transactions on visualization and computer graphics 16*, 6 (2010), 990–998. 3

[MOA*08] MIESENBERGER K., OSSMANN R., ARCHAMBAULT D., SEARLE G., HOLZINGER A.: More than just a game: accessibility in computer games. In *Symposium of the Austrian HCI and usability engineering group* (2008), Springer, pp. 247–260. 1, 2

[PK13] PORTER J. R., KIENTZ J. A.: An empirical study of issues and barriers to mainstream video game accessibility. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility* (Bellevue Washington, Oct. 2013), ACM, pp. 1–8. doi:10.1145/2513383.2513444. 2

[Squ03] SQUIRE K.: Video games in education. *Int. J. Intell. Games & Simulation 2*, 1 (2003), 49–62. 1

[Sza17] SZAFIR D. A.: Modeling color difference for visualization design. *IEEE transactions on visualization and computer graphics 24*, 1 (2017), 392–401. 9

[vgc] Game charts. https://www.vgchartz.com/gamedb/. Accessed: 2021-09-30. 3

[whi] Accessibility in games: Motivations and approaches. https://igda-gasig.org/wp-content/uploads/2011/10/igda_accessibility_whitepaper.pdf. Accessed: 2021-10-30. 2

[Won11] WONG B.: Salience to relevance. *Nature Methods 8*, 11 (Nov 2011), 889–889. URL: https://doi.org/10.1038/nmeth.1762, doi:10.1038/nmeth.1762. 3

[YFH11] YUAN B., FOLMER E., HARRIS F. C.: Game accessibility: A survey. *Universal Access in the Information Society 10*, 1 (Mar. 2011), 81–100. doi:10.1007/s10209-010-0189-5. 2

[Zam08] ZAMMITTO V.: VISUALIZATION TECHNIQUES IN VIDEO GAMES. In *Electronic Visualisation and the Arts (EVA 2008)* (July 2008). doi:10.14236/ewic/EVA2008.30. 1, 2