Hearing the Bullseye: An Auditory-Cued Archery Exergame for the Visually Impaired and Their Sighted Family and Friends

Shan Luo
School of Design & Innovation,
China Academy of Art
Hangzhou, China
luoshan3398@qq.com

Jianan Johanna Liu
School of Design & Innovation,
China Academy of Art
Hangzhou, China
liujianan705@outlook.com

Botao Amber Hu*
Reality Design Lab
New York City, USA
botao@reality.design

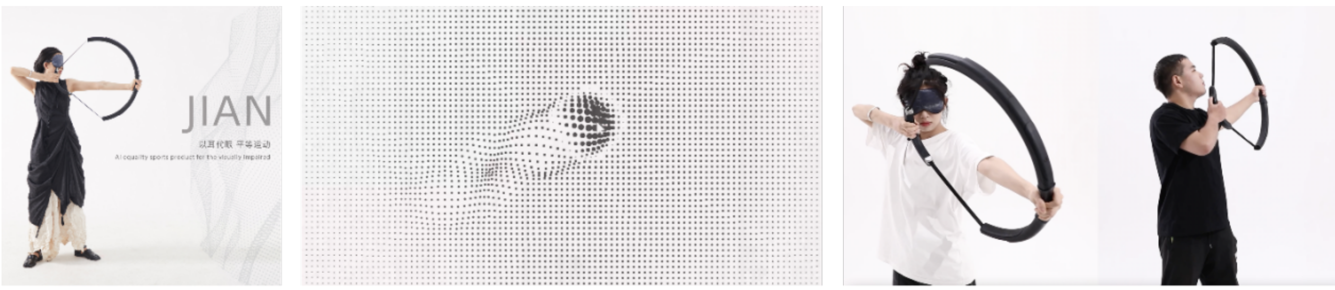

Figure 1: "Hearing the Bullseye", an archery exergame designed for harmonious play between VI individuals and their sighted family and friends. (Left) Demonstration of user interaction in "Hearing the Bullseye"; (Middle) Visual feedback in the interface for sighted users, without revealing the actual location of the bullseye; (Right) Both sighted and visually impaired players participating in the two-player mode

ABSTRACT

How can blind and sighted individuals play together? The natural disparity in visual abilities often poses challenges for fair competition in social play. This can diminish the confidence of visually impaired (VI) individuals and reduce engagement for sighted players. While previous literature has incorporated fairness design strategies for the VI, we additionally aim to address the potential problem of boredom for sighted players by providing enhanced visual feedback without compromising fairness as a novel design strategy. We present *"Hearing the Bullseye"*, an archery exergame designed for harmonious play between VI individuals and their sighted family and friends. Players use a bow equipped with an infrared sensor, allowing them to target an unseen bullseye using sound rather than sight. An empirical study involving 18 sighted and VI participants demonstrated that the design strategies used in *"Hearing the Bullseye"* effectively promote social engagement among both groups while ensuring fair competition.

*Corresponding author; also serves as a visiting lecturer at the School of Design & Innovation, China Academy of Art.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.
CHI PLAY Companion '24, October 14–17, 2024, Tampere, Finland
© 2024 Copyright held by the owner/author(s). Publication rights licensed to ACM.
ACM ISBN 979-8-4007-0692-9/24/10
https://doi.org/10.1145/3665463.3678829

CCS CONCEPTS

• **Human-centered computing → Accessibility theory, concepts and paradigms**; **Interaction design theory, concepts and paradigms**; *Interaction paradigms.*

KEYWORDS

Visually Impaired, Exergames, Design Strategy, Accessibility, Auditory Feedback

ACM Reference Format:
Shan Luo, Jianan Johanna Liu, and Botao Amber Hu. 2024. Hearing the Bullseye: An Auditory-Cued Archery Exergame for the Visually Impaired and Their Sighted Family and Friends. In *Companion Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY Companion '24), October 14–17, 2024, Tampere, Finland.* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3665463.3678829

1 INTRODUCTION

According to WHO [1], over a billion people worldwide live with some form of visual impairment (VI). As inclusive design of technology for people with VI advances in the context of the Third Wave HCI [51, 77], research emphasis on social adaptation for the VI and their interactions with sighted individuals has increased [46, 76, 81]. Often, VI individuals have fewer opportunities to participate in physical social activities with sighted family and friends. This can lead to feelings of social isolation, which can affect their quality of life and social relationships . Research suggests that social exergames[35, 62, 73] involving VI individuals and their sighted family and friends can improve both physiological and psychological well-being [12, 18, 25, 27, 45, 48], and enhance social relationships [41, 58, 67, 71, 72, 74]. This understanding has resulted in significant contributions to social exergames by researchers in the field [11, 30, 43, 44, 52–55].

How can VI and sighted individuals play together? VI can often result in imbalances and asymmetries between VI and sighted players during gameplay [25, 34, 37, 63]. Sighted players tend to make concessions, while VI players may worry about becoming overly reliant on others [8, 17, 34]. This imbalance can discourage VI players from initiating interactions [33, 34], and may cause sighted players to feel bored or overly considerate, preventing them from enjoying the game with the same winning goal as the impaired. This behavior not only undermines the confidence of VI players, but also discourages sighted players from engaging with them, creating barriers to spontaneous social gameplay [15, 38, 75]. Numerous researchers have contributed to this field [4, 7, 11, 13, 16, 22, 24, 29, 30, 32, 36, 42, 44, 47, 52, 55, 60, 66, 70, 78]. Games such as VI-Bowling [54] and VI-Tennis [53] use auditory or tactile interactions to reduce the imbalance between players. Electronic games that incorporate 3D spatial audio have been developed [2, 11, 20, 30, 39, 52]. These games allow both VI and sighted individuals to enjoy video gaming, including family-oriented casual games [30]. Despite technological advancements, many games still fail to address competitive imbalance and asymmetry, which compromise fairness. Often, these games result in sighted individuals taking on a supportive role, leading to disinterest among both VI and sighted players. This unaddressed research gap leaves significant design space for games, with technology ready to further address the imbalance in social play between VI and sighted individuals, while ensuring fairness for the VI and maintaining engagement of the sighted.

Combining previous research, we have identified two major challenges in the design space of social play games involving blind and sighted individuals.

(C1) *Fairness for the VI*. The inherent imbalance in visual abilities presents challenges for fair competition for the VI. This can diminish the gaming experience for the VI, leading to a lack of confidence and a less engaging social game experience.

(C2) *Boredom for the sighted*. In traditional social games for VI and sighted players, sighted players often adopt a supportive and accommodating role towards VI players. Sighted players need more effective feedback to prevent the gameplay from feeling unengaging or boring when playing with the VI.

Based on the challenges and design needs faced by blind and sighted individuals in games, we have developed *"Hearing the Bullseye"*, an archery simulation game that places blind and sighted players on the same level, allowing for equal competition through auditory cues. Players use a vibration bow equipped with infrared sensors to aim at an invisible target, with changes in sound frequency indicating proximity to the target, thus guiding them to complete the shot. The game uses sensory compensation to allow both parties to play through the same sensory interactions, addressing the asymmetry between them. Additionally, the game emphasizes that sighted players need more game effect feedback than blind players to prevent boredom during the game.

Finally, we conducted empirical studies in a booth at a design exhibition. Over a five-day period, we invited 18 VI and sighted participants to play the game and evaluate the effectiveness of our design work. The event attracted a significant audience and received enthusiastic cheers from the public. Our primary contributions include:

- *Innovative archery exergame for VI and their sighted player*: We've created an archery game with auditory cues, allowing fair competition for VI and sighted players, addressing social play challenges.
- *Maintain balance*: We've proposed a game that balance social games between VI and sighted players, enabling VI players to fully experience the game, while enhancing feedback for sighted players.
- *Insights for future research on social exergames for the VI and the sighted*: Our game design and the game strategies offer valuable insights for future inclusive game design research catering to diverse sensory abilities.

2 RELATED WORKS

2.1 Traditional simple social games for VI

Simple community-organized events and activities that enhance the interaction abilities of the VI [9, 17, 19, 31, 69]. To prevent injury from excessive physical movement among the VI and to consider the high cost of action training in some activities, most community-organized events tend to be straightforward. Examples include 'Movie Description' [68], 'role-playing exercise' [61].

Apparently, These social activities do not consider the inherent imbalance in interactions between VI and sighted individuals. VI participants still rely on sighted individuals for assistance during the activities, failing to showcase their capabilities. Meanwhile, sighted participants often play a supportive role, and frequently find the feedback from the game effects to be boring [25, 34, 37, 63].

2.2 Modified versions of traditional games for VI

In recent years, the development of numerous accessible technologies [3, 10, 26, 28, 56, 57, 73] has provided both VI and sighted individuals with a richer and more varied array of social play settings, enhancing their ways of interaction. For example, modified versions of traditional board games [14, 21], such as the simplified mobile multiplayer card game based on conventional card rules developed by Hanseul Cho and others [21], allow both VI and sighted individuals to enjoy gaming together. For instance,*Front Row* is an immersive audio broadcast application designed for VI audiences to enjoy tennis matches [42]. Dorothea Reusser and others have designed a device for VI individuals: *Feeling Fireworks* [66]. VI individuals can also engage in special social activities, such as participating in social events at museums [5, 6] and marine parks [47], and co-creating music games with sighted individuals [49, 60].

However, in most of these social interactions, VI and sighted individuals are part of two separate game interaction systems. They do not use the same senses simultaneously to complete the game, and many do not fully consider the level of interaction between the parties, or the interaction is not yet sufficiently deep. the unfriendly game interactions or purely auditory games make it difficult for sighted players to adapt to completing games through sound alone, reducing interaction between sighted and VI players. This approach often leads to an increased imbalance between the two groups.

2.3 Highly interactive sport games for VI

Research confirms that sports-related social interactions not only help VI individuals overcome visual barriers to participating in various sports activities, but also provide opportunities for socializing with sighted individuals [4, 13, 13, 16, 16, 22, 23, 26, 64, 65, 70]. Numerous studies have used assistive technology to enhance interactions between visually impaired and sighted individuals in activities like Sonic-Badminton for physical and social engagement [44], and games replacing visual with auditory and tactile feedback such as VI Bowling and VI Tennis [53, 54]. Leisure activities include eyes-free yoga developed with Kinect [62] and a 2D action game for both sighted and visually impaired users [52], along with social experiences like enjoying live football matches together [59]. Glinert and Wyse [30] developed an accessible video game named *AudiOdyssey*, co-developed by VI and sighted developers. This game utilizes the Nintendo Wii remote and provides feedback through auditory cues, allowing both VI and sighted players to play together. Drew Berge and others demonstrated an audio-based mobile game, *Pingball* [11], which offers all players, including those with VI, the traditional pinball experience. In these activities, the interactions and collaborations between VI and sighted individuals are closely knit and carry significant social value [79].

Although these types of sport games have already addressed the imbalance in game interaction mechanisms between VI and sighted players to some extent, and sighted players receive stronger feedback on game effects compared to electronic games, as sighted players, there is still a need for enhanced feedback on the effects produced in the game. This enhancement is necessary to increase the enjoyment for sighted players, preventing boredom and allowing both parties to enjoy the fun brought by social play. Our research aims to explore more possibilities based on this foundation.

3 DESIGN

Based on our preliminary study, which looked at preferences and challenges of VI and sighted individuals in social games, we introduced *"Hearing the Bullseye"*, a motion-sensing archery game that uses sound feedback to locate the target center on the screen. Combining the principles of ability-based design [40, 50, 80], we designed the interaction method of *"Hearing the Bullseye"* to better support the sighted and VI to experience the archery sports game. As the bow gets closer to the center, the sound frequency increases, aiding in precise aiming. This game levels the playing field for VI and sighted players and provides enhanced visual feedback for sighted players upon hitting the target, making the game enjoyable for everyone.

3.1 Interaction design

3.1.1 Start archery. Players face the screen and draw the bow. They hear audio feedback and see a cursor when the game starts. As the bowstring tightens, the handle vibrates, helping visually impaired (VI) players. Sighted players see the cursor, making the game accessible to everyone using various sensory cues.

3.1.2 Listen to the bullseye. Each round, the bullseye appears randomly. Players track it by changes in sound frequency: higher as they near the target and lower when farther. This method trains spatial perception, helping both visually impaired (VI) and sighted players improve their spatial awareness.

3.1.3 Listen and shoot. Players release the bow when the sound frequency is highest, indicating the bullseye's location. A successful hit results in bright lights and positive sounds, while a miss leads to dim lights and negative sounds, encouraging another attempt.

3.2 Game levels and two-player mode

Figure 2 shows the game design Corresponding levels and two-player modes are provided to encourage players to continue to experience the fun of the game and competition.

- First Level: Players locate a normal-sized bullseye using the sound frequency.
- Second Level: The bullseye size is reduced, increasing the difficulty as players must be more precise.
- Third Level: The normal-sized bullseye moves randomly every ten seconds, requiring players to locate and shoot the target quickly.
- Two-Player Mode: Players must distinguish the sound from their own bow and locate the bullseye by sound frequency within a set time. The player with the most successful shots wins. Hits are marked by specific sound and light effects, and a new target appears randomly after each hit. Misses require players to reset by pulling the bow again. This mode emphasizes the ability of VI players to differentiate correct sounds from background noise and allows sighted players to experience the auditory challenges VI players face.

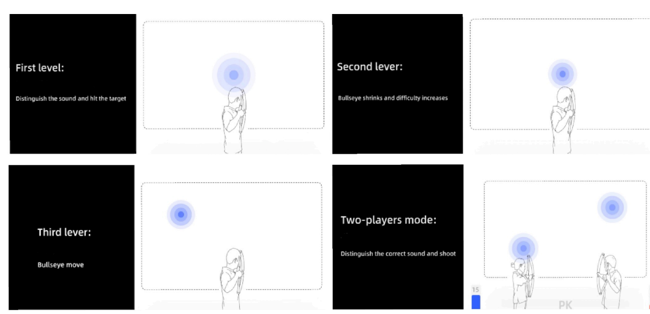

Figure 2: The working examples of Bullseye level and two-player mode: (a) First level. (b) Second pass. (c) Third pass. (d) Two-player mode.

4 EVALUATION

We evaluated "Hearing the Bullseye" to assess its effectiveness and user experience. The study involved VI and sighted participants

Participant ID	Gender	Age	Visual Condition	Occupation	Familiarity of Archery (1-5)
V1	Male	25	Low vision	Freelancing	2 : Slightly familiar
S1	Female	26	Normal vision	Nurse	2 : Slightly familiar
V2	Female	30	Low vision	VI masseur	1 : Not at all familiar
S2	Male	21	Normal vision	Student	3 : Moderately familiar
S3	Male	28	Normal vision	Artist	4 : Very familiar
V3	Female	21	VI	Student	1: Not at all familiar
V4	Female	30	Half VI	Freelancing	1: Not at all familiar
S4	Male	35	Normal vision	Writer	1 : Not at all familiar
S5	Female	18	Normal vision	Student	4 : Very familiar
V5	Female	31	VI	Voice Artist	1 : Not at all familiar
V6	Female	28	Low vision	Freelancing	2 : Slightly familiar
V7	Male	27	VI	Voice customer service	2 : Slightly familiar
S6	Female	32	Normal vision	Influencer	3 : Moderately familiar
S7	Female	29	Normal vision	Reporter	1 : Not at all familiar
S8	Male	25	Normal vision	Teacher	2 : Slightly familiar
V8	Female	43	Low vision	VI masseur	3 : Moderately familiar
V9	Male	29	VI	VI masseur	1: Not at all familiar
S9	Male	31	Normal vision	Civil servant	3 : Moderately familiar

Table 1: Summary of Participants

who provided insights into the game's accessibility and enjoyment, as shown in Figure3.

4.1 Participants and Environment

We recruited 9 visually impaired (VI) individuals from the local association for VI volunteers and 9 sighted participants through social media and snowball sampling, with participants varying in visual abilities and familiarity with games. An 8x8 meter indoor space was prepared, with walls and floor serving as projection areas for the game. The space included areas for spectators and was equipped with immersive projectors and audio devices. Multiple cameras recorded player experiences and audience reactions. Six volunteers were recruited for various roles, including video recording, commentary, training, and data documentation.

4.2 Procedure

Figure 3: Photos from the *"Hearing the Bullseye"* user experiments

4.2.1 Game Rule Explanation. Both sighted and VI players were taught game controls through live demonstrations, verbal instructions, and physical actions. Sighted players received a 5-minute tutorial, while VI players were taught using tactile methods and sound cues.

4.2.2 Game testing. Game testing included single and dual-player modes. Each participant completed three levels of increasing difficulty, with data recorded to evaluate shooting accuracy. Two-player matches paired VI and sighted players randomly until one hit the target.

4.2.3 Interviews. Post-game feedback was gathered through semi-structured interviews, focusing on players' overall experience, perceptions of fairness, and reactions to the game's effects.

4.3 Data and Analysis

From our user experiments, we collected both quantitative and qualitative data to evaluate whether "Hearing the Bullseye" addresses the primary challenges for VI and sighted players in social play games. Insights were derived from gameplay data and semi-structured interviews.

4.3.1 Single-player Game Segment Data . We analyzed the completion counts and times for players V1 to V9 and S1 to S9. Data from the game system's backend provided a detailed view of each player's performance in the archery component, as shows in Table 2.

- Level 1. All players successfully completed the first level, indicating a good understanding of the game rules.
- Level 2. Increased difficulty resulted in a higher failure rate, with most players initially completing the task.
- Level 3. This level posed significant challenges, with only a few players successfully navigating it. VI players typically excelled due to their reliance on auditory cues, giving them a distinct advantage.

Participant ID	Level 1	Level 2	Level 3	Visual Condition
V1	✓	✓	✓	Low vision
S1	✓			Normal vision
V2	✓	✓		Low vision
S2	✓	✓		Normal vision
S3	✓	✓		Normal vision
V3	✓			Blind
V4	✓	✓	✓	Half Blind
S4	✓			Normal vision
S5	✓	✓		Normal vision
V5	✓	✓	✓	Blind
V6	✓	✓		Low vision
V7	✓			Blind
S6	✓	✓		Normal vision
S7	✓	✓	✓	Normal vision
S8	✓	✓		Normal vision
V8	✓	✓		Low vision
V9	✓	✓		Blind
S9	✓	✓	✓	Normal vision

Table 2: Single-player Game Mode

4.3.2 VI vs Sighted Match Segment Data . Participants were categorized by visual status and paired randomly for one-on-one battles. Detailed data in Table3 from these encounters illustrated the outcomes and performance metrics.

Rounds	Player 1	Player 2	Result
1	V1	S7	VI wins
2	V2	S5	Sighted wins
3	V3	S1	Sighted wins
4	V7	S8	Sighted wins
5	V6	S2	VI wins
6	V4	S6	VI wins
7	V5	S3	VI wins
8	V9	S9	Sighted wins
9	V8	S4	VI wins

Table 3: Two-player Match Segment Data

VI players won six out of nine matches, showcasing their adeptness in adapting to the game and stimulating interest among sighted participants. These outcomes demonstrate that our design strategy successfully addresses fairness issues and engages sighted players with innovative gameplay elements.

4.4 Findings

Semi-structured interviews, lasting between 20 to 30 minutes, focused on participants' feedback about their experiences with "Hearing the Bullseye" under our design strategy. We observed players' time spent, emotional changes, and game outcomes. Thematic analysis was used to construct themes encapsulating participants' experiences.

Engagement and Enjoyment. Both VI and sighted reported high levels of engagement and enjoyment. The immersive experience and competitive elements kept players interested and motivated throughout the sessions.

Accessibility and Fairness. VI players found the audio cues intuitive and essential for gameplay, while sighted players appreciated the visual feedback. The design was praised for creating a fair playing field, where VI players often excelled due to the reliance on sound.

Social Interaction. The game fostered significant social interaction, especially in the two-player mode. Sighted participants gained a better understanding of the challenges faced by VI players, promoting empathy and cooperation.

Skill Development. Players noted improvements in spatial awareness and timing. VI participants, in particular, felt the game helped enhance their auditory spatial skills.

Suggestions for Improvement. Feedback included desires for more levels, additional sound customization options, and enhanced feedback mechanisms to further refine the experience and challenge levels.

5 DISCUSSIONS AND FUTURE WORKS

Our evaluation has confirmed the effectiveness of *"Hearing the Bullseye,"* validating our design strategies and setting a foundation for further research. Based on our study, we suggest the following improvements:

- **Spatial audio:** Incorporate 3D spatial audio effects for enhanced feedback, as suggested by VI users.
- **Home accessibility:** Make the game more accessible by integrating a toy bow with smartphones and adding multiplayer AR, reducing setup complexity and cost.
- **More social exergames:** Expand to other sports-themed games like VI golf, fishing, or kite flying, applying our design strategies to enhance social play for VI and sighted players.
- **Audience engagement:** Develop games that incorporate bystander cheers and participation, enhancing the shared experience and motivation for VI players.

6 CONCLUSIONS

In this study, our game *"Hearing the Bullseye"* — an auditory-cued, partially visual-feedback, tactile-feedback archery game — successfully validated our proposed design strategies. This game greatly improved fairness between VI and sighted players in social gaming scenarios. It boosted the confidence of VI players while also enhancing engagement for sighted players. This ensured the game was engaging for all players. Through innovative interaction, the game resolved issues of unfairness and prevented the gaming experience from becoming boring for sighted players. It provided a valuable social communication bridge for both groups. In addition, our research offers new design strategies and practical insights into social game design, particularly in facilitating effective interactions and understanding between players of varying abilities.

7 ACKNOWLEDGMENTS

This research was funded by the National Social Science Fund of China, major project in arts (Grant Number: 20ZD09)

REFERENCES

[1] 2024. Vision Impairment and Blindness. https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment.

[2] Troy Allman, Rupinder K. Dhillon, Molly A.E. Landau, and Sri H. Kurniawan. 2009. Rock Vibe: Rock Band® Computer Games for People with No or Limited Vision. In *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Pittsburgh Pennsylvania USA, 51–58. https://doi.org/10.1145/1639642.1639653

[3] Ronny Andrade, Jenny Waycott, Steven Baker, and Frank Vetere. 2021. Echolocation as a Means for People with Visual Impairment (PVI) to Acquire Spatial Knowledge of Virtual Space. *ACM Transactions on Accessible Computing* 14, 1 (March 2021), 1–25. https://doi.org/10.1145/3448273

[4] Cédric Anthierens, Didier Groux, and Vincent Hugel. 2018. Sensory navigation guide for visually impaired sea kayakers. *Journal of Field Robotics* 35, 5 (2018), 732–747.

[5] Saki Asakawa, João Guerreiro, Dragan Ahmetovic, Kris M. Kitani, and Chieko Asakawa. 2018. The Present and Future of Museum Accessibility for People with Visual Impairments. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (Galway, Ireland) *(ASSETS '18)*. Association for Computing Machinery, New York, NY, USA, 382–384. https://doi.org/10.1145/3234695.3240997

[6] Saki Asakawa, João Guerreiro, Daisuke Sato, Hironobu Takagi, Dragan Ahmetovic, Desi Gonzalez, Kris M. Kitani, and Chieko Asakawa. 2019. An Independent and Interactive Museum Experience for Blind People. In *Proceedings of the 16th International Web for All Conference* (San Francisco, CA, USA) *(W4A '19)*. Association for Computing Machinery, New York, NY, USA, Article 30, 9 pages. https://doi.org/10.1145/3315002.3317557

[7] Saki Asakawa and Amy Hurst. 2021. "What Just Happened?": Understanding Non-visual Watching Sports Experiences. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Virtual Event USA, 1–3. https://doi.org/10.1145/3441852.3476525

[8] Matthew T. Atkinson, Sabahattin Gucukoglu, Colin H. C. Machin, and Adrian E. Lawrence. 2006. Making the mainstream accessible: redefining the game. In *Proceedings of the 2006 ACM SIGGRAPH Symposium on Videogames* (Boston, Massachusetts) *(Sandbox '06)*. Association for Computing Machinery, New York, NY, USA, 21–28. https://doi.org/10.1145/1183316.1183321

[9] Mauro Avila, Katrin Wolf, Anke Brock, and Niels Henze. 2016. Remote Assistance for Blind Users in Daily Life: A Survey about Be My Eyes. In *Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments* (Corfu, Island, Greece) *(PETRA '16)*. Association for Computing Machinery, New York, NY, USA, Article 85, 2 pages. https://doi.org/10.1145/2910674.2935839

[10] Cynthia L. Bennett. 2018. A Toolkit for Facilitating Accessible Design with Blind People. *ACM SIGACCESS Accessibility and Computing* 120 (Jan. 2018), 16–19. https://doi.org/10.1145/3178412.3178415

[11] Drew Berge, Danilo Bettencourt, Stanley Lageweg, Willie Overman, Amir Zaidi, and Rafael Bidarra. 2020. Pinball for the Visually Impaired – an Audio Spatialization and Sonification Mobile Game. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play*. ACM, Virtual Event Canada, 43–46. https://doi.org/10.1145/3383668.3419919

[12] Elaine Biddiss and Jennifer Irwin. 2010. Active video games to promote physical activity in children and youth: a systematic review. *Archives of pediatrics & adolescent medicine* 164, 7 (2010), 664–672.

[13] Faine Bisset. 2016. *The lived experience of university students with visual impairments and their sighted partners' participation in inclusive social ballroom dance.* Ph. D. Dissertation. Stellenbosch: Stellenbosch University.

[14] Adrian Bolesnikov, Jin Kang, and Audrey Girouard. 2022. Understanding Tabletop Games Accessibility: Exploring Board and Card Gaming Experiences of People who are Blind and Low Vision. In *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '22)*. Association for Computing Machinery, New York, NY, USA, Article 21, 17 pages. https://doi.org/10.1145/3490149.3501327

[15] Brian Bors. 2015. The current state of game accessibility guidelines. *Library Catalog: www. game-accessibility. com* (2015), 7.

[16] Boni Boswell, Bomna Ko, and Seok Yoon. 2023. Experiences and motivations of dancers with and without disabilities in inclusive dance. *Sport, Education and Society* 28, 5 (2023), 508–521.

[17] Erin Brady, Meredith Ringel Morris, Yu Zhong, Samuel White, and Jeffrey P. Bigham. 2013. Visual challenges in the everyday lives of blind people. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 2117–2126. https://doi.org/10.1145/2470654.2481291

[18] Michele Capella-McDonnall. 2007. The need for health promotion for adults who are visually impaired. *Journal of Visual Impairment & Blindness* 101, 3 (2007), 133–145.

[19] Melissa A Chase. 2001. Children's Accuracy of Self-Appraisal of Ability and Motivational Beliefs in Physical Education. *The Physical Educator* 58, 2 (2001), 103–103.

[20] Jean F.P. Cheiran, Luciana Nedel, and Marcelo S. Pimenta. 2011. Inclusive Games: A Multimodal Experience for Blind Players. In *2011 Brazilian Symposium on Games and Digital Entertainment*. IEEE, Salvador, Bahia, TBD, Brazil, 164–172. https://doi.org/10.1109/SBGAMES.2011.24

[21] Hanseul Cho, Kyudong Park, and Seungmoon Choi. 2018. Equal-Level Interaction: A Case Study for Improving User Experiences of Visually-Impaired and Sighted People in Group Activities. In *2018 IEEE International Symposium on Haptic, Audio and Visual Environments and Games (HAVE)*. IEEE, Dalian, 1–6. https://doi.org/10.1109/HAVE.2018.8547502

[22] Triston Cooper, Heather Lai, and Jenna Gorlewicz. 2022. Do You Hear What I Hear: The Balancing Act of Designing an Electronic Hockey Puck for Playing Hockey Non-Visually. *ACM Trans. Access. Comput.* 15, 1, Article 4 (mar 2022), 29 pages. https://doi.org/10.1145/3507660

[23] Kirk Andrew Crawford, Katta Spiel, and Foad Hamidi. 2023. Complex Dynamics: Disability, Assistive Technology, and the LGBTQIA+ Community Center Experience in the United States. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–15. https://doi.org/10.1145/3597638.3608401

[24] Frederico da Rocha Tomé Filho, Pejman Mirza-Babaei, Bill Kapralos, and Glaudiney Moreira Mendonça Junior. 2019. Let's Play Together: Adaptation Guidelines of Board Games for Players with Visual Impairment. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3290605.3300861

[25] Madhuka De Silva, Sarah Goodwin, Leona Holloway, and Matthew Butler. 2023. Understanding Challenges and Opportunities in Body Movement Education of People who are Blind or have Low Vision. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '23)*. Association for Computing Machinery, New York, NY, USA, Article 11, 19 pages. https://doi.org/10.1145/3597638.3608409

[26] Madhuka De Silva, Sarah Goodwin, Leona Holloway, and Matthew Butler. 2023. Understanding Challenges and Opportunities in Body Movement Education of People Who Are Blind or Have Low Vision. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–19. https://doi.org/10.1145/3597638.3608409

[27] Ansgar E. Depping, Regan L. Mandryk, Colby Johanson, Jason T. Bowey, and Shelby C. Thomson. 2016. Trust Me: Social Games are Better than Social Icebreakers at Building Trust. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. Association for Computing Machinery, New York, NY, USA, 116–129. https://doi.org/10.1145/2967934.2968097

[28] Bhanuka Gamage, Thanh-Toan Do, Nicholas Seow Chiang Price, Arthur Lowery, and Kim Marriott. 2023. What Do Blind and Low-Vision People Really Want from Assistive Smart Devices? Comparison of the Literature with a Focus Study. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–21. https://doi.org/10.1145/3597638.3608955

[29] Anurag Ghosh, Suriya Singh, and C. V. Jawahar. 2017. Towards Structured Analysis of Broadcast Badminton Videos. arXiv:1712.08714 [cs.CV]

[30] Eitan Glinert and Lonce Wyse. 2007. AudiOdyssey: An Accessible Video Game for Both Sighted and Non-Sighted Gamers. In *Proceedings of the 2007 Conference on Future Play - Future Play '07*. ACM Press, Toronto, Canada, 251. https://doi.org/10.1145/1328202.1328255

[31] A Jonathan R Godfrey and M Theodor Loots. 2015. Advice from blind teachers on how to teach statistics to blind students. *Journal of Statistics Education* 23, 3 (2015).

[32] David Gonçalves, Manuel Piçarra, Pedro Pais, João Guerreiro, and André Rodrigues. 2023. "My Zelda Cane": Strategies Used by Blind Players to Play Visual-Centric Digital Games. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, Hamburg Germany, 1–15. https://doi.org/10.1145/3544548.3580702

[33] David Gonçalves, André Rodrigues, and Tiago Guerreiro. 2020. Playing With Others: Depicting Multiplayer Gaming Experiences of People With Visual Impairments. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 22, 12 pages. https://doi.org/10.1145/3373625.3418304

[34] David Gonçalves, André Rodrigues, Mike L. Richardson, Alexandra A. de Sousa, Michael J. Proulx, and Tiago Guerreiro. 2021. Exploring Asymmetric Roles in Mixed-Ability Gaming. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 114, 14 pages. https://doi.org/10.1145/3411764.3445494

[35] Andreas Grabski, Toni Toni, Tom Zigrand, Rene Weller, and Gabriel Zachmann. 2016. Kinaptic - Techniques and Insights for Creating Competitive Accessible 3D Games for Sighted and Visually Impaired Users. In *2016 IEEE Haptics Symposium (HAPTICS)*. IEEE, Philadelphia, PA, 325–331. https://doi.org/10.1109/HAPTICS.2016.7463198

[36] Juan Haladjian, Maximilian Reif, and Bernd Brügge. 2017. VIHapp: a wearable system to support blind skiing. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers* (Maui, Hawaii) *(UbiComp '17)*. Association for Computing Machinery, New York, NY, USA, 1033–1037. https://doi.org/10.1145/3123024.3124443

[37] John Harris and Mark Hancock. 2019. To Asymmetry and Beyond! Improving Social Connectedness by Increasing Designed Interdependence in Cooperative Play. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300239

[38] John Harris, Mark Hancock, and Stacey D. Scott. 2016. Leveraging Asymmetries in Multiplayer Games: Investigating Design Elements of Interdependent Play. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. Association for Computing Machinery, New York, NY, USA, 350–361. https://doi.org/10.1145/2967934.2968113

[39] Akio Honda, Hiroshi Shibata, Jiro Gyoba, Kouji Saitou, Yukio Iwaya, and Yôiti Suzuki. 2007. Transfer effects on sound localization performances from playing a virtual three-dimensional auditory game. *Applied Acoustics* 68, 8 (2007), 885–896.

[40] Katherine Isbister. 2016. *How games move us: Emotion by design.* Mit Press.

[41] Katherine Isbister, Ulf Schwekendiek, and Jonathan Frye. 2011. Wriggle: An Exploration of Emotional and Social Effects of Movement. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*. ACM, Vancouver BC Canada, 1885–1890. https://doi.org/10.1145/1979742.1979919

[42] Gaurav Jain, Basel Hindi, Connor Courtien, Xin Yi Therese Xu, Conrad Wyrick, Michael Malcolm, and Brian A. Smith. 2023. Front Row: Automatically Generating Immersive Audio Representations of Tennis Broadcasts for Blind Viewers. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology*. ACM, San Francisco CA USA, 1–17. https://doi.org/10.1145/3586183.3606830

[43] Rushil Khurana, Ashley Wang, and Patrick Carrington. 2021. Beyond Adaptive Sports: Challenges & Opportunities to Improve Accessibility and Analytics. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Virtual Event USA, 1–11. https://doi.org/10.1145/3441852.3471223

[44] Shin Kim, Kun-pyo Lee, and Tek-Jin Nam. 2016. Sonic-Badminton: Audio-Augmented Badminton Game for Blind People. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, San Jose California USA, 1922–1929. https://doi.org/10.1145/2851581.2892510

[45] Ksenia Kolykhalova, Paolo Alborno, Antonio Camurri, and Gualtiero Volpe. 2016. A serious games platform for validating sonification of human full-body movement qualities. In *Proceedings of the 3rd International Symposium on Movement and Computing* (Thessaloniki, GA, Greece) *(MOCO '16)*. Association for Computing Machinery, New York, NY, USA, Article 39, 5 pages. https://doi.org/10.1145/2948910.2948962

[46] Axel Leblois. 2021. The DARE Index - Monitoring the Progress of Digital Accessibility around the World - A Research Conducted by Advocates for Advocates. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Virtual Event USA, 1–1. https://doi.org/10.1145/3441852.3487959

[47] Huaigu Li, Jon Bellona, Leslie Smith, Amy Bower, and Jessica Roberts. 2023. "Let the Volcano Erupt!": Designing Sonification to Make Oceanography Accessible for Blind and Low Vision Students in Museum Environment. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–6. https://doi.org/10.1145/3597638.3614482

[48] Lauren Lieberman and Elaine McHugh. 2001. Health-Related Fitness of Children who are Visually Impaired. *Journal of Visual Impairment and Blindness* 95 (05 2001), 272–287. https://doi.org/10.1177/0145482X0109500503

[49] Leon Lu, Karen Anne Cochrane, Jin Kang, and Audrey Girouard. 2023. "Why Are There so Many Steps?": Improving Access to Blind and Low Vision Music Learning through Personal Adaptations and Future Design Ideas. *ACM Transactions on Accessible Computing* 16, 3 (Sept. 2023), 1–20. https://doi.org/10.1145/3615663

[50] Martin Maguire. 2001. Methods to Support Human-Centred Design. *International Journal of Human-Computer Studies* 55, 4 (Oct. 2001), 587–634. https://doi.org/10.1006/ijhc.2001.0503

[51] Jennifer Mankoff, Kelly Avery Mack, Jason Wiese, Kirk Andrew Crawford, and Foad Hamidi. 2023. A11yFutures: Envisioning the Future of Accessibility Research. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–4. https://doi.org/10.1145/3597638.3615652

[52] Masaki Matsuo, Takahiro Miura, Ken-ichiro Yabu, Atsushi Katagiri, Masatsugu Sakajiri, Junji Onishi, Takeshi Kurata, and Tohru Ifukube. 2021. Inclusive Action Game Presenting Real-time Multimodal Presentations for Sighted and Blind Persons. In *Proceedings of the 2021 International Conference on Multimodal Interaction*. ACM, Montréal QC Canada, 62–70. https://doi.org/10.1145/3462244.3479912

[53] Tony Morelli, John Foley, Luis Columna, Lauren Lieberman, and Eelke Folmer. 2010. VI-Tennis: A Vibrotactile/Audio Exergame for Players Who Are Visually Impaired. In *Proceedings of the Fifth International Conference on the Foundations of Digital Games*. ACM, Monterey California, 147–154. https://doi.org/10.1145/1822348.1822368

[54] Tony Morelli, John Foley, and Eelke Folmer. 2010. Vi-Bowling: A Tactile Spatial Exergame for Individuals with Visual Impairments. In *Proceedings of the 12th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Orlando Florida USA, 179–186. https://doi.org/10.1145/1878803.1878836

[55] Tony Morelli and Eelke Folmer. 2011. Real-Time Sensory Substitution to Enable Players Who Are Blind to Play Video Games Using Whole Body Gestures. In *Proceedings of the 6th International Conference on Foundations of Digital Games*. ACM, Bordeaux France, 147–153. https://doi.org/10.1145/2159365.2159385

[56] Cecily Morrison, Edward Cutrell, Martin Grayson, Elisabeth Rb Becker, Vasiliki Kladouchou, Linda Pring, Katherine Jones, Rita Faia Marques, Camilla Longden, and Abigail Sellen. 2021. Enabling Meaningful Use of AI-infused Educational Technologies for Children with Blindness: Learnings from the Development and Piloting of the PeopleLens Curriculum. In *Proceedings of the 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Virtual Event USA, 1–13. https://doi.org/10.1145/3441852.3471210

[57] Cecily Morrison, Martin Grayson, Rita Faia Marques, Daniela Massiceti, Camilla Longden, Linda Wen, and Edward Cutrell. 2023. Understanding Personalized Accessibility through Teachable AI: Designing and Evaluating Find My Things for People Who Are Blind or Low Vision. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–12. https://doi.org/10.1145/3597638.3608395

[58] Melanie Nind. 2014. *What is inclusive research?* https://doi.org/10.5040/9781849668149

[59] Hiroyuki Ohshima, Makoto Kobayashi, and Shigenobu Shimada. 2021. Development of Blind Football Play-by-play System for Visually Impaired Spectators: Tangible Sports. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–6. https://doi.org/10.1145/3411763.3451737

[60] Shotaro Omori and Ikuko Eguchi Yairi. 2013. Collaborative Music Application for Visually Impaired People with Tangible Objects on Table. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Bellevue Washington, 1–2. https://doi.org/10.1145/2513383.2513403

[61] Scott Plous. 2000. Responding to overt displays of prejudice: A role-playing exercise. *Teaching of Psychology* 27, 3 (2000), 198–200.

[62] Kyle Rector, Cynthia L. Bennett, and Julie A. Kientz. 2013. Eyes-Free Yoga: An Exergame Using Depth Cameras for Blind & Low Vision Exercise. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Bellevue Washington, 1–8. https://doi.org/10.1145/2513383.2513392

[63] Kyle Rector, Lauren Milne, Richard E. Ladner, Batya Friedman, and Julie A. Kientz. 2015. Exploring the Opportunities and Challenges with Exercise Technologies for People who are Blind or Low-Vision. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility* (Lisbon, Portugal) *(ASSETS '15)*. Association for Computing Machinery, New York, NY, USA, 203–214. https://doi.org/10.1145/2700648.2809846

[64] Georg Regal, David Sellitsch, Simone Kriglstein, Simon Kollienz, and Manfred Tscheligi. 2020. Be Active! Participatory Design of Accessible Movement-Based Games. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, Sydney NSW Australia, 179–192. https://doi.org/10.1145/3374920.3374953

[65] Georg Regal, David Sellitsch, Simone Kriglstein, Simon Kollienz, and Manfred Tscheligi. 2020. Be Active! Participatory Design of Accessible Movement-Based Games. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Sydney NSW, Australia) *(TEI '20)*. Association for Computing Machinery, New York, NY, USA, 179–192. https://doi.org/10.1145/3374920.3374953

[66] Dorothea Reusser, Espen Knoop, Roland Siegwart, and Paul Beardsley. 2017. Feeling Fireworks. In *Adjunct Publication of the 30th Annual ACM Symposium on User Interface Software and Technology*. ACM, Québec City QC Canada, 65–66. https://doi.org/10.1145/3131785.3131811

[67] James H Rimmer. 2006. Building inclusive physical activity communities for people with vision loss. *Journal of Visual Impairment & Blindness* 100, 1_suppl (2006), 863–865.

[68] Anna Rohrbach, Atousa Torabi, Marcus Rohrbach, Niket Tandon, Christopher Pal, Hugo Larochelle, Aaron Courville, and Bernt Schiele. 2017. Movie Description. *International Journal of Computer Vision* 123, 1 (May 2017), 94–120. https://doi.org/10.1007/s11263-016-0987-1

[69] L Rosengren and C Undemar. 2001. *Can I play with you? How visually impaired children and young people experience their social situation.* Technical Report. Report.

[70] Masaaki Sadasue, Daichi Tagami, Sayan Sarcar, and Yoichi Ochiai. 2021. Blind-Badminton: A Working Prototype to Recognize Position of Flying Object for Visually Impaired Users. In *Universal Access in Human-Computer Interaction. Access to Media, Learning and Assistive Environments: 15th International Conference, UAHCI 2021, Held as Part of the 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings, Part II*. Springer-Verlag, Berlin, Heidelberg, 494–506. https://doi.org/10.1007/978-3-030-78095-1_36

[71] Katie Sell, Tia Lillie, and Julie Taylor. 2008. Energy Expenditure During Physically Interactive Video Game Playing in Male College Students With Different Playing Experience. *Journal of American college health : J of ACH* 56 (03 2008), 505–11. https://doi.org/10.3200/JACH.56.5.505-512

[72] Deborah R. Shapiro, Aaron Moffett, Lauren Lieberman, and Gail M. Dummer. 2005. Perceived Competence of Children with Visual Impairments. *Journal of Visual Impairment & Blindness* 99, 1 (2005), 15–25. https://doi.org/10.1177/0145482X0509900103 arXiv:https://doi.org/10.1177/0145482X0509900103

[73] Garth Shoemaker, Takayuki Tsukitani, Yoshifumi Kitamura, and Kellogg S. Booth. 2010. Body-Centric Interaction Techniques for Very Large Wall Displays. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*. ACM, Reykjavik Iceland, 463–472. https://doi.org/10.1145/1868914.1868967

[74] Viktor Stadler and Helmut Hlavacs. 2018. Blind Adventure - A Game Engine for Blind Game Designers. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '18)*. Association for Computing Machinery, New York, NY, USA, 503–509. https://doi.org/10.1145/3242671.3242703

[75] Moira E Stuart, Lauren Lieberman, and Karen E Hand. 2006. Beliefs about physical activity among children who are visually impaired and their parents. *Journal of Visual Impairment & Blindness* 100, 4 (2006), 223–234.

[76] Sarit Felicia Anais Szpiro, Shafeka Hashash, Yuhang Zhao, and Shiri Azenkot. 2016. How People with Low Vision Access Computing Devices: Understanding Challenges and Opportunities. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, Reno Nevada USA, 171–180. https://doi.org/10.1145/2982142.2982168

[77] Arthur Theil, Craig Anderton, Chris Creed, Nasrine Olson, Raymond John Holt, and Sayan Sarcar. 2023. Accessibility Research and Users with Multiple Disabilities or Complex Needs. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–6. https://doi.org/10.1145/3597638.3615651

[78] Roman Voeikov, Nikolay Falaleev, and Ruslan Baikulov. 2020. TTNet: Real-time temporal and spatial video analysis of table tennis. arXiv:2004.09927 [cs.CV]

[79] Jacob O. Wobbrock, Shaun K. Kane, Krzysztof Z. Gajos, Susumu Harada, and Jon Froehlich. 2011. Ability-Based Design: Concept, Principles and Examples. *ACM Transactions on Accessible Computing* 3, 3 (April 2011), 1–27. https://doi.org/10.1145/1952383.1952384 https://dl.acm.org/doi/10.1145/1952383.1952384.

[80] Jacob O. Wobbrock, Shaun K. Kane, Krzysztof Z. Gajos, Susumu Harada, and Jon Froehlich. 2011. Ability-Based Design: Concept, Principles and Examples. *ACM Trans. Access. Comput.* 3, 3, Article 9 (apr 2011), 27 pages. https://doi.org/10.1145/1952383.1952384

[81] Lotus Zhang, Simon Sun, and Leah Findlater. 2023. Understanding Digital Content Creation Needs of Blind and Low Vision People. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ACM, New York NY USA, 1–15. https://doi.org/10.1145/3597638.3608387