Co-Design of an Adaptive User Interface for the Visually Impaired People

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***Abstract*—This article presents an adaptable 2D interface for visually impaired people. Its goal is to enable them to recognize 3D objects on a simple computer screen. This alternative to 3D or immersive glasses, which are difficult for visually impaired individuals to use, offers 2D renderings of 3D objects enhanced by image processing. It leverages the richness of information inherent in 3D objects without relying on segmentation and voice transcription. It also allows for customization of the 2D interface and personalization based on the visual impairment condition. The article discusses the co-design with visually impaired of the 2D interface and the evaluation of its usability.**

Keywords—Adaptive user interfaces; Design methods; Interface design for people with disabilities; Usability testing and evaluation.

I. Introduction

This article presents the co-design process with the visually impaired of an Adaptive 2D Visualization Interface. The visual impairment is defined by the World Health Organization when visual acuity is less than 3/10 after optical correction and/or when the visual field is less than 10°. This population is inherently heterogeneous. Each person has her specificities and perceives things uniquely. They use their residual vision in their daily activities when possible [22].

This work aims to use the residual vision of the visually impaired to improve 3D object recognition.

To explore and recognize 3D objects, various solutions exist, such as the use of 3D glasses or VR headsets, but these devices are difficult to use for the visually impaired [18].

We propose an alternative device adapted to visually impaired people, based on the use of an ordinary 2D screen without semantic segmentation and voice transcription.

To make the recognition of 3D objects possible on 2D screens, the renderings of 3D objects are augmented by image processing and a suitable interface. The interface then offers visually impaired, visualization aids (outlines, zoom, lighting effects, etc.) and settings functions (menu choice, font, background, etc.).

Section II describes the general co-design process, considerations for the visually impaired, and provides a state of the art of existing visualization interfaces adapted for this audience. Section III details our interface co-design with our visual impaired and the tools used by us. Section IV describes our 2D visualization interface and Section V presents its evaluation. We conclude with our research perspectives.

II. Research Context

A. Co-design

Co-design is a method that involves the end user in the product design and development process. This design is multidisciplinary, collective and collaborative [5]. Co-design stems from user-centered design. It aims to gather user input and convert it into design choices. The co-design cycle is divided into four phases [25].

1. <u>The analysis phase</u> identifies user's needs. The tools used are document studies, questionnaires, interviews and observation methods.
2. <u>The ideation phase</u> allows collaboration, contribution and creativity. The tools used are brainstorming, brainwriting and focus groups.
3. <u>The design phase</u> defines the appropriate functionalities to be developed. This phase results in the proposal of a high-fidelity prototype with interface specifications and the features. The tools used include paper or digital mock-ups. The development is then carried out following a spiral development cycle [6] incorporating design testing to validate both features and the interface.
4. <u>The evaluation phase</u> values the final application and measures the user's satisfaction (usability and usefulness criteria). The user-centered, heuristic, and analytical evaluations can be employed [4][11].

When the co-design is dedicated to the design of products for a specific disability is named inclusive co-design [19] and the tools used in four phases are not suitable.

B. Considerations for co-design with the visually impaired

For a sighted person, the field of view is very wide [10]. The processing of information perceived by sight is parallel. This is much more challenging, or even impossible, for visually impaired who compensate their deficiency through the sense of touch and/or hearing.

The problem is that the tactile perceptual field is less efficient than sight for Braille reading tasks, as it made up of successive and discontinuous elements [28]. For example, when a visually impaired person reads a document, he or she has to rely mainly on memory and exert significant effort to memorize. This is due to the fact that they do not have a global vision of the text's structure [9].

In contrast to the persistent nature of sight, auditory perception operates through a mode of analysis that is considered fleeting. Auditory memory in the visually

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impaired therefore entails a high cognitive load, as it is sequential in nature [12].

The co-design tools available for visually impaired must consider their sensory perception. Reference [1] recommend observation and oral interviews, specifying that anything involving paper must be excluded. Reference [7] emphasize the careful use of brainstorming to avoid fatiguing visually impaired. Reference [26] recommend the use of high-fidelity software prototypes.

C. *Visualization Interfaces for the Visually Impaired*

2D interfaces now offer numerous accessibility features [3][23]. Windows users have, for example, access to features such as screen reading, improved contrast, and magnification.

3D interfaces by using augmented or virtual reality can assist visually impaired allow visual experiences of the real world. In augmented reality, "ForeSee" prototype allows users of virtual reality headsets to zoom in, enhance and invert contrasts in real-time [30]. This device lacks an interface for activating these features; users must verbally request them. Other visual augmentation systems in augmented reality, such as the one proposed by [14] involving Google Glass to enhance contrast perception through edge detection.

Similarly, the device by Hicks et al. aims to improve depth perception for obstacle avoidance [13]. Google Glass has a minimal interface for setting edge detection and displaying edge type. System in [13] has no interface, as its sole purpose is to enhance the depth of objects between them.

In virtual reality, [31] have developed "SeeingVR", a framework of 14 features to enrich the visual experience in virtual reality video games with assistive functions such as magnification, edge detection, contrast enhancement, voice description of annotated objects or text to speech. Similar to "ForeSee", the selection and adjustment of treatments are done through a voice input system, without an interface, which can lead to a poor gaming experience.

The utilization of virtual reality headsets can pose challenges for individuals with visual impairments. System latency, stemming from computational processes, along with inaccurate distance perception, contributes to difficulties in headset usage [17].

We offer an alternative to immersive visualization systems for viewing 3D objects on a simple computer screen. This 2D interface offers a range of accessibility features to meet the specific needs of the visually impaired. Our ambition is to provide an enhanced visual experience while avoiding the drawbacks associated with existing immersive systems. Our interface also takes advantage of the wealth of information inherent in 3D objects without the need for semantic segmentation and voice transcription.

III. CO-DESIGNING THE INTERFACE

A. *Selection of tools for Visually Impaired participants*

As highlighted in section I-B, to design the interface 2D, we selected co-design tools suitable for visually impaired. We chose tools that depend on hearing but do not involve too much cognitive load, as recommended by [1].

Interviews encourage interaction and discussion. They can be directive (based closed questions), semi-directive (open questions), or free (the interviewee chooses the themes).

Direct observation is a mediation tool to collect verbal and behavioral data (video capture and field diary).

Brainstorming aims to generate ideas orally, and relies on spontaneous creativity.

Software prototype (digital mock-up). For the development phase, we adopted an iterative development approach using successive cycles (spirals), based from the spiral model [6]. In each iteration, the prototype is evaluated through design tests. Evaluators check if the objectives are achieved and decide on new objectives if necessary. This process allows for continuous risk assessment, ensures quality, and limits the number of spirals.

User-centered evaluations focus on the utility and difficulty level (assessed through questionnaires, interviews, and electronic monitoring) and also assessing the understanding of terminology.

Nielsen's and Bastien & Scapin's heuristic evaluations use evaluation grids to inspect usability (ergonomics, standards, controls, etc.) [4][21].

B. *Analysis phase*

First, we studied pathologies and various forms of visual impairment. We used "OpenViSim" [15] to simulate their vision and better understand the visual perception of partially sighted. We focused on the main pathologies: retinitis pigmentosa (impaired peripheral vision), retinopathy (vision obstructed by spots), age-related macular degeneration (impaired central vision), cataracts (severe myopia).

Then, we conducted semi-structured interviews with 10 visually impaired to gather their needs and expectations. The interviews consisting of questions divided into 3 themes: visual perception, expectations, needs in terms of viewing 3D objects. They lasted on average one hour. The analysis of these interviews highlighted that all participants use tools to assist them in daily tasks (mobility, object identification, reading content, etc.). They use, when they can their residual vision. Additionally, when using digital tools, they express dissatisfaction with the lack of adaptation and personalization, admitting that in some cases, it does not really help them.

C. *Ideation phase*

The ideation phase continued with brainstorming sessions. During these sessions, we ensured that our participants were not cognitively overloaded: limited duration to a maximum of one and a half hours, in the morning, with regular breaks, in small groups, allowing time for speaking, reformulating, writing down ideas, and repeating them orally.

These sessions led to a list of the 2D interface specifications: interface setting *(customize fonts, object background and menus)* and visualization functions *(zoom, appearance, outlines, static and dynamic lightning, and texture substitution)*.

Only five fonts have been selected: Arial, Liberation, Luciol, Tiresias and OpenDys, to limit an overloaded selection menu (demand of visually impairs) and to align with the minimalism criterion [21]. Arial and Liberation are frequently

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used fonts in the daily lives of visually impaired individuals. Luciole and Tiresias are recommended for all pathologies [20]. OpenDys is a font for dyslexic persons but used also by visually impaired. This font improve readability by making letters more distinct and less likely to blend together. This font, like all sans-serif fonts is recommended for the visually impaired as it improves readability by making letters more distinct and less likely to blend [24].

Four highly contrasted colour themes have been chosen for the menus: white *(white background and elements, black fonts and outlines)*, light gray *(light gray background, white elements, black fonts and outlines)*, dark gray *(dark gray background, black elements, white fonts and outlines)* and black *(black background and elements, white fonts and outlines).* They are important for retinopathy and cataracts because they improve readability and distinction between interface elements. Adjustments to the thickness of menu and button borders have been chosen to improve item detection.

We've also added the ability to customize the background scene contrast, the menu which can be placed on the left or on the right side of the screen. Regarding the interface elements, the use of buttons, sliders, dropdowns are possible adhering to standards for visually impaired accessibility [29].

The visualization functions selected to help recognize 3D objects compensated for loss of detail, contrast or sharpness, color alteration and distorted depth perception. The digital treatments use the geometric data of 3D objects or the luminosity information obtained after 2D rendering. Seven functions requiring minimal parameterization on the part of the visually impaired have been selected: digital zoom, navigation around the object and automatic framing, sharpness and contrast, brightness and saturation, outlines, texture, play of lights.

D. *Design phase*

We developed a software prototype, with Unity, following a spiral cycle. We wanted people to interact with the prototype without going through digital simulation, where interactions are predefined. Unity is a cross-platform game engine used in virtual/augmented reality [27]. Its native features include the ability to create 2D/3D renderings, design user interfaces and customize them. The visual rendering quality and performance of applications can be optimized using shaders. Shaders enable the implementation of special effects such as post-processing without compromising performance.

Three design test cycles were carried out to produce the 2D visual interface presented in next section. The second cycle approved the interface setting. The third cycle validated the visualization functions.

During these tests, interviews based on semi-structured questions were conducted. The duration was approximately one hour, always in the morning with regular breaks. A free-form interview concluded the session to gather verbal suggestions. Direct observation (with video) was also used.

IV. 2D Interface Description

A. *Visualization functions*

Among the available visualization functions, object navigation enhances the perception of 3D dimensions. Combined with digital zoom, it allows for enlarging a specific part of the object, thereby providing a detailed view.

The appearance adjustment functions (sharpness, saturation, brightness, contrast) help minimize visual injury. They enhance details, adjust brightness differences between light and dark areas, and limit glare.

The outlines functions enhance important structural elements such as the silhouette, pronounced color variations, or changes in the curvature of the object's surface. They facilitate the understanding of the object's characteristic features without relying on vocal cues.

Lighting effects utilize cast shadows to enhance the perception of spatial dimension. They can be either static or dynamic to reduce navigation operations.

Texture substitution alters an object's visual appearance, aiding comprehension by eliminating reflections and enhancing spatial dimension perception.

All features can be combined according to preferences and needs. A detailed presentation of these treatments can be found in [2].

Figure 1 shows a treatment applied to a 3D object: a cactus. The screenshot on the left shows the 3D object without pathology. The middle screenshot shows the object as seen by a visually impaired person suffering from myopia and tunnel vision. The screenshot on the right shows the 3D object with edge computed from colour gradient to delineate and identify the other small cactus.

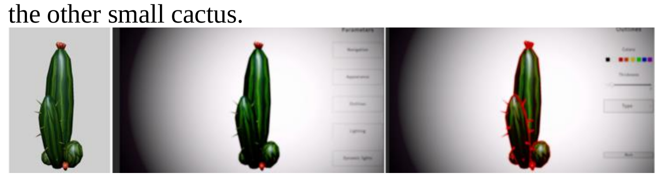

Figure 1. Screenshot, the cactus plant without processing (on the left) and with treatments (on the right): edge computed from colour gradient.

B. *2D interface settings*

Interface settings allows the visually impaired to modify fonts, menus, and object background. Figure 3 shows examples of interface configurations: menu position, background color and font choice.

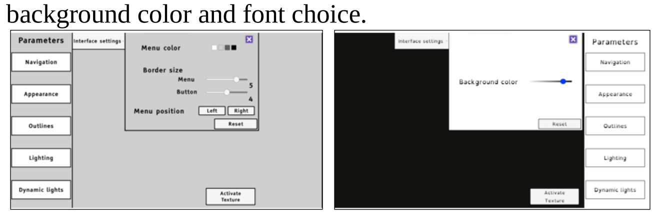

Figure 2. On the left, the menu is on the left, the background is grey, the menu theme is light grey and the font is Luciole. On the right, the menu is on the right, with a black background, white theme and OpenDys font.

V. 2D Interface Evaluation

A. Evaluation criteria

The evaluation of the interface focused on usability and utility criteria [11]. Usability ensures interface clarity, customization simplicity and easy navigation. Structured menus, clear instructions and minimal elements enhance usability by improving accessibility and functions memorization. Utility evaluates how visual enhancement functions contribute to improving users' perception of 3D models. The results of the utility evaluation are detailed in [2].

To assess the usability of the interface, we utilize the ergonomic evaluation grids by Bastien and Scapin (ergonomic criteria) and Nielsen (heuristic), which we combine [16] to extract criteria that we evaluate based on end-user satisfaction [8]. This allows participants to indicate whether they are satisfied with the interface and find it accessible. We have compiled these criteria in a table entitled "Criteria Composition" [32]. The criteria we have selected for usability evaluation are ease of use (is the interface easy to manipulate?), interface minimalism (do the presented information not cause visual overload?), reactivity (does the interface provide immediate feedback?), adherence to standards and clear designation, and finally flexibility (does the interface adapt to visual preferences and technological habits?).

B. Final evaluator

Four visually impaired as end users have been involved in the evaluation phase, whose visual conditions are in Table I. These persons did not participate in the co-design of the tool. The participants have different visual conditions, but some similarities can still be observed: P2 and P3 have retinitis pigmentosa, P3 and P4 have only half of their visual field).

TABLE I. PARTICIPANT INFORMATION IN THE FINAL EVALUATION.

Participants	P1	P2	P3	P4
Pathologies	Nystagmus	Pigmentary retinopathy	Pigmentary retinopathy Scotoma	Meningioma Optic nerve atrophy
Visual acuity	Left: 1/10 Right: 1/10	Left: 1/20 Right: 4/10	Left: blind Right: 1/10	Left: blind Right: 1/20
Visual field	Total	Tunnel vision	Tunnel vision, blind spot effect	Cannot see out of right part in the right eye
Light sensitivity	Yes	Yes	Yes	Yes
Color vision	Good	Need contrasts	Need contrasts	Need contrasts

C. Protocol and evaluation

The evaluation sessions lasted on average 1 hour and 30 minutes and were recorded. They were structured as follows: collection of visual conditions (as found in Table I), presentation of interface customization and visual enhancement functions, followed by a task to test interface usage, which involved exploring 7 3D models (unannotated) representing everyday objects.

To present the interface customization and visual enhancement functions, we asked the participants to navigate autonomously within the interface and activate these functions. We began by configuring the interface, asking them to adjust the fonts, then the menus, and finally the object background. Next, we asked them to activate and adjust the visual enhancement functions to explore them.

We used evaluation grids (in the form of semi-structured interviews) to assess the interface [33]. Participants could respond "Yes", "No", or "Not really", and were encouraged to share their feelings and comments throughout the session. We also considered user preferences by observing their interface usage while adjusting the interface rendering. Additionally, we gathered participants' feelings through open-ended questions at the end of the evaluation.

D. Results and analysis

We evaluated 80 questions regarding the usability of the interface. The criterion "Ease of Use" (includes 20 questions) concerns the use of interface elements. "Interface Minimalism" (21 questions) concerns visual information overload. "Reactivity" (3 questions) concerns real-time feedback. "Adherence to Standards and Clear Designation" (8 questions) concerns the understanding of the interface through standards and labels. Finally, "Flexibility" (18 questions) concerns the adaptation of the interface to users, both in terms of visual and usage preferences.

To assess participant satisfaction based on our criteria, we calculated the average of responses categories to the questions for each criterion. Figure 4 summarizes the participants' responses, in percentages, for these criteria. These results confirm that the usability is highly satisfactory ("yes" responses are above 75% for all criteria).

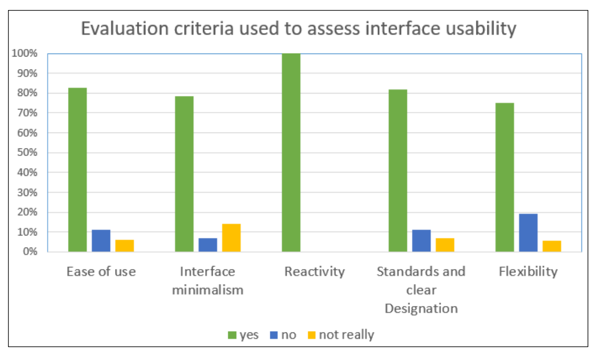

Figure 3. The response rate of participants per evaluation criterion.

Additionally, we analyzed the reasons behind the "no" and "not really" responses for each question to extract qualitative information. We won't delve into the analysis of the 5 criteria here. Instead, we focus of the following 3 criteria: "Ease of Use", "Interface Minimalism", and "Flexibility".

Participants found the interface "easy to use" (83% according to Figure 4). The difficulties encountered are specific to participant's visual condition. Participants with reduced vision indicated that they did not appreciate using sliders. In response to the question "*Is selecting a choice via slider suitable?*", P3 answered "no", stating that "*I need some adaptation time because the elements are too small"*, and P4 answered "not really", specifying that the sliders are "*disruptive"*. They do not perceive the changes well when moving the slider cursor due to a lack of perception of visual changes (difficulty in distinguishing variations) and precision (coordination or depth perception issues). Participants with retinitis pigmentosa do not appreciate the use of the dropdown menu. They both answered "no" to the question "*Is selecting a choice via dropdown menu suitable?*", stating that the font size is too small and the scroll bar is not sufficiently contrasted.

It is also noteworthy that the checkbox is the most difficult element to use for 3 participants, regardless of their visual conditions. One participant answered "no" to the question "*Is selecting a choice via checkbox suitable?*" and the other 2 answered "not really". This element is too small, and the difference between selecting and deselecting is not significant. Additionally, all participants expressed a desire to be able to adjust the size and contrast of the mouse cursor to facilitate interaction with the interface.

We weren't surprised by feedback on the choice of elements. Visually impaired users prefer buttons to checkboxes, which are more difficult to use because they are smaller and less customizable. Adjustment of the mouse cursor was also planned and will be integrated into a future version of the interface.

Regarding the "minimalism of the interface", participants found that the interface is not visually overloaded (77% according to Figure 4). Visual information overload also corresponds to participants' visual conditions.

When participants have reduced vision, they experience reduced visual acuity (which can lead to blurred vision), limited spatial perception, and low-contrast perception. They find that interface elements are small and have difficulty positioning the mouse pointer on these elements. For example, in response to the question "*Does visualization via dropdown menu suit and not overload?*", they both answered "no" and specified that it is because of the font size. Participants with retinitis pigmentosa prefer the harmonization of interface elements or menus: they answered "yes" to the question "*Do you want harmonization of interface elements?*".

We found that the interface settings are correlated with the pathology categories of the visually impaired. The visual impaired those with similar pathologies have common preferences.

For the "flexibility", participants find that the interface adapts to their visual and technological preferences (75% according to Figure 4). All participants found the font size too small, even when increased to the maximum. We also collected the interface settings for each participant. After presenting the interface and its functions, they can adjust the interface as they wished. The settings for each participant are summarized in Table II below.

The interface settings for these four participants are all different. The uniqueness of these settings illustrates the link between the participants' visual conditions and their needs and preferences for interface rendering. Participants suffering from retinal pigmentary disorders (participants P2 and P3 in Tables I and II) preferred the interface in a "dark" theme, with a dark background for the 3D objects. Participants with reduced vision (P3 and P4 in the Tables) preferred bold text because reading is difficult for them.

The interface rendering parameter choices highlight the importance of customizing interfaces to meet the individual needs of visually impaired with similar characteristics. Integrating visually impaired user profiles would allow pre-setting the interface and avoiding visual injury when launching the interface.

TABLE II. INTERFACE SETTINGS CHOSEN BY EACH PARTICIPANT[a]

Elements		P1	P2	P3	P4
Font	Type	Luciole	Luciole	Luciole	Luciole
	Size	4	10 (max)	10 (max)	10 (max)
	Bold	No	No	Yes	Yes
Menu	Theme	White	Black	Black	White
	Menu borders	5 (max)	2	5 (max)	5 (max)
	Button borders	5 (max)	1 (min)	5 (max)	5 (max)
	Menu position	Left	Left	Left	Right
3D model background		White	Dark gray	Black	White

a. All participants customized the interface to suit their individual needs. Similarities in the choice of settings were observed, especially among participants with similar visual conditions.

All participants answered "yes" to "*Is the application accessible to you?*". Furthermore, they were all able to perform the task of exploring the 3D models without help, thanks to the interface customized to their needs.

VI. Conclusion and Future Work

This article presents a visualization interface for 3D objects designed for visually impaired individuals, using a standard 2D screen. This interface offers configuration functions and visualization aids to best utilize the residual vision of visually impaired individuals. It was evaluated by four end users with various visual impairments.

The results show that the usability is satisfactory for more than 75% for the five selected criteria. Future developments of the interface will involve adjusting the font size, using buttons instead of checkboxes, and supporting navigation both with the mouse and keyboard to ensure maximum accessibility. We propose to take into account in the user's profile the characteristics that enable parameters to be initialized according to the main pathologies.

Future perspectives will focus on visualization aid functionalities aimed at highlighting the symmetry properties of 3D objects (important in the natural object recognition process by humans).

References

[1] J. Albouys-Perrois, J. Laviole, C. Briant, and A. M. Brock, "Towards a multisensory augmented reality map for blind and low vision people: A participatory design approach", in *Proceedings of the Conference on human factors in computing systems - CHI '18*, Montreal, QC, Canada: ACM, Apr. 2018, pp. 1-14. doi: https://doi.org/10.1145/3173574.3174203. Retrieved: April 10, 2024.

[2] A. Ambles, D. Leclet-Groux, A. Potelle, and E. M. Mouaddib, "Computer vision serving visually impaired people" in *International Symposium on Signal, Image, Video, and Communications - ISICV*, in press.

[3] R. Ani, E. Maria, J. J. Joyce, V. Sakkaravarthy and M. A. Raja, "Smart Specs: Voice assisted text reading system for visually impaired persons using TTS method" in *Proceedings of the International Conference on Innovations in Green Energy and Healthcare Technologies – ICIGEHT '17*, Coimbatore, India, IEEE, Mar. 2017, pp. 1-6. Retrieved: April 10, 2024.

[4] C. Bastien and D. Scapin, "Ergonomic criteria for the evaluation of human-computer interfaces", Doctoral dissertation, Inria, RT-0156, INRIA. 1993, pp. 79.

[5] S. Bφdker, K. Grφnbæk, and M. Kyng, "Cooperative design: techniques and experiences from the Scandinavian scene" in *Readings in human-computer interaction*, Morgan Kaufmann Publishers, pp. 215-224, 1995. doi: https://doi.org/10.1016/B978-0-08-051574-8.50025-X. Retrieved: April 10, 2024.

[6] B. W. Boehm, "A spiral model of software development and enhancement", *Computer*, IEEE, vol. 21, no. 5, pp. 61-72, May 1988. doi: 10.1109/2.59. Retrieved: April 10, 2024.

[7] A. Brock et al., "Methods and tools for participatory design with blind users" in *Proceedings of the 22nd Conference on Human-Computer Interaction – IHM '10*, Luxembourg, Luxembourg: ACM, Sept. 2010, pp. 65-72. doi: https://doi.org/10.1145/1941007.1941017. Retrieved: April 10, 2024 (in French).

[8] C. Deephouse, D. Goldenson, M. Kellner, and T. Mukhopadhyay, "The effects of software processes on meeting targets and quality" in *Proceedings of the Twenty-Eighth Hawaii International Conference on System Sciences - HICSS*, IEEE, vol. 4, pp. 710-719, Jan. 1995. doi: 10.1109/HICSS.1995.375677. Retrieved: April 10, 2024.

[9] A. Dufresne, O. Martial, and C. Ramstein, "Multimodal user interface system for blind and "visually occupied" users: Ergonomic evaluation of the haptic and auditive dimensions" in Proceeding of Human-Computer Interaction - Inteact'95, Lillehammer, Norway, 1995, pp. 163-168.

[10] J. J. Gibson, "The ecological approach to visual perception: classic edition", *Psychology Press*, First edition, 2014. ISBN : 978-0898599596.

[11] M. Grislin, and C. Kolski, "Evaluation of human-machine interfaces during interactive system development ", *Journal of Information Sciences and Technologies - TSI Series: Computer Techniques and Science*, vol. 15, no. 3, pp. 265-296, 1996. (in French).

[12] Y. Hatwell, "Images and non-visual spatial representations in the blind", in *Colloquium French National Institute of Health and Medical Research - INSERM*, John Libbey Eurotext Ltd, vol. 228, pp. 13-35, 1993.

[13] S. L. Hicks et al., "A depth-dased head-mounted visual display to aid navigation in partially sighted individuals", *PLoS ONE*, vol. 8, no. 7, pp. 1-8, Jul. 2013. doi: https://doi.org/10.1371/journal.pone.0067695. Retrieved: April 10, 2024.

[14] A. D. Hwang and E. Peli, "An augmented-reality edge enhancement application for google glass" *Optometry and Vision Science*, vol. 91, issue 8, pp. 1021-1030, Aug. 2014. doi: 10.1097/OPX.0000000000000326. Retrieved: April 10, 2024.

[15] P. R. Jones and G. Ometto, "Degraded reality: using VR/AR to simulate visual impairments," in *Proceedings IEEE Workshop on Augmented and Virtual Realities for Good - VAR4Good*, Reutlingen, Germany, IEEE, Mar. 2018, pp. 1-4. Retrieved: April 10, 2024.

[16] M. Maguire, "Methods to support human-centred design", *International journal of human-computer studies*, vol. 55, no. 4, pp. 587-634, 2001.

[17] M. Morel, B. Bideau, J. Lardy, and R. Kulpa, "Advantages and limitations of virtual reality for balance assessment and rehabilitation", *Clinical Neurophysiology*, vol. 45, issues 4–5, pp. 315-326, 2015. ISSN 0987-7053. Retrieved: April 10, 2024.

[18] M. Mott et al., "Accessible by design: an opportunity for virtual reality" in *2019 IEEE International Symposium On Mixed And Augmented Reality Adjunct - ISMAR-Adjunct*, Beijing, China, IEEE, Oct. 2019, pp. 541-545. doi:10.1109/ismar-adjunct.2019.00122. Retrieved: April 10, 2024.

[19] B. Nanchen et al., "Designing with and for people with disabilities: towards an integrated and transdisciplinary approach to inclusive design" in *Vulnerabilities and emerging risks: thinking and acting together for sustainable transformation: Proceedings of the 56th SELF Congress*, Genève, Suisse, Jul. 2022, pp. 371-377.

[20] F. Navamuel, "Three fonts designed for the visually impaired", in *ICT Tools*, Apr. 2023. Retrieved: April 10, 2024. [Online]. Available from: https://outilstice.com/2020/02/3-polices-de-caracteres-concues-pour-les-malvoyants/. (in French).

[21] J. Nielsen, "Heuristic evaluation", in J. Nielsen et R.L. Mack (Eds.), *Usability inspection methods*, New York, John Wiley & Sons, ACM, Chapter 2, pp. 25-62, 1994.

[22] R. M. A. van Nispen et al., "Low vision rehabilitation for better quality of life in visually impaired adults", in *Cochrane Database of Systematic Reviews 2020*, issue 1, no. CD006543 Jan. 2020. doi: https://doi.org/10.1002/14651858.CD006543.pub2. Retrieved: April 10, 2024.

[23] N. Parikh, I. Shah, and S. Vahora, "Android smartphone based visual object recognition for visually impaired using deep learning" in *2018 international conference on communication and signal processing – ICCSP*, Chennai, India, IEEE, Apr. 2018, pp. 420-425. doi: 10.1109/ICCSP.2018.8524493. Retrieved: April 10, 2024.

[24] E. Russell-Minda et al., "The legibility of typefaces for readers with low vision: A research review" in *Journal of Visual Impairment & Blindness*, vol. 101, issue 7, pp. 402-415, Jul. 2007. doi: https://doi.org/10.1177/0145482X0710100703. Retrieved: April 10, 2024.

[25] D. Schuler and A. Namioka, "Participatory design: principles and practices," in *CRC Press*, 1993.

[26] R. Sefelin, M. Tscheligi, and V. Giller, "Paper prototyping-what is it good for? A comparison of paper-and computer-based low-fidelity prototyping", in *Proceedings of CHI'03 extended abstracts on Human factors in computing systems - CHI '03*, Lauderdale, Florida, USA, ACM, Apr. 2003, pp. 778-779. doi: https://doi.org/10.1145/765891.765986. Retrieved: April 10, 2024.

[27] Unity. Retrieved: April 10, 2024. [Online]. Available from: https://unity.com/fr

[28] I. Verjat, "The functional cerebral asymmetry in manual tactilo-kinesthetic modality", *The Psychological Year*, vol. 88, no. 1, pp. 83-109, 1988. (in French).

[29] W3C Web Accessibility Initiative (WAI), 2024. Retrieved: April 10, 2024. [Online]. Available from: https://www.w3.org/WAI/ARIA/apg/patterns/

[30] Y. Zhao, S. Szpiro, and S. Azenkot, "Foresee: a customizable head-mounted vision enhancement system for people with low vision", in Proceedings of the 17th international ACM SIGACCESS Conference on Computers & Accessibility – ASSETS '15, ACM, Oct. 2015, pp. 239-249. doi: https://doi.org/10.1145/2700648.2809865. Retrieved: April 10, 2024.

[31] Y. Zhao et al., "SeeingVR: a set of tools to make virtual reality more accessible to people with low vision", in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems – CHI '19*, ACM, May 2019, pp. 1-14. doi: https://doi.org/10.1145/3290605.3300341. Retrieved: April 10, 2024.

[32] The table of the "Criteria Composition". Created: March 2024. [Online]. Available from: https://extra.u-picardie.fr/nextcloud/index.php/s/AyrQzfsMgrDtJ7y

[33] The interface evaluation grids. Created: March 2024. [Online]. Available from: https://extra.u-picardie.fr/nextcloud/index.php/s/AyrQzfsMgrDtJ7