Two sides of the same coin: accessibility practices and neurodivergent users experience of extended reality

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Purpose: This paper explores the accessibility barriers faced by neurodivergent individuals regarding the use of Extended Reality (XR) technologies and the difficulties faced by developers in creating neurodivergent inclusive XR experiences.
Design: We carried out a survey with neurodivergent participants, and a series of semi-structured interviews with neurodivergent adults and XR developers.
Findings: Neurodivergent individuals experience sensory overload when using XR technologies, these negative experiences are exacerbated by excessive multisensory stimulation. Allowing for the customization of sensory settings was seen as the only way to potentially limit negative experiences. We found that XR developers lacked awareness of accessibility requirements and struggled to integrate them in current software development practices.
Originality: There is a lack of studies exploring how neurodivergent individuals experience XR considering their different sensory processing patterns. There is also no research exploring XR developers' awareness of accessibility needs of neurodivergent individuals. This paper presents an account of the challenges faced by neurodivergent XR users, the difficulties faced by XR developers to integrate neurodivergent accessibility requirements, and proposes specific strategies to overcome challenges.
Social implications: Accessibility understanding regarding neurodivergence is increasingly available and it is the time to bring computing and information services within the reach of all neurodivergent individuals. It is crucial that the power in the design of XR is decentralized from neurotypical XR developing practices to avoid artificial barriers that decrease the quality of life

Keywords: Neurodiversity, Neurodivergence, Extended Reality, Virtual Reality, Accessibility, Metaverse

Introduction

The interest and application of Extended Reality (XR) technologies, including Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) has boomed in recent years with huge increment in popularity across different markets, from gaming and education, to customer services and workplaces (Bohil *et al.*, 2011; Meagan Shelley, n.d.; Zweifach and Triola, 2019). With VR, AR and MR becoming mainstream, more and more people use these technologies in personal and professional settings within their everyday lives (Funk *et al.*, 2017; Oyelude, 2018; Ripamonti *et al.*, 2021). However, XR technologies rely on immersive multisensory stimulations, and it is unclear how these affect people who have different sensory processing patterns.

Neurodiversity is an umbrella term that represents the neurological variability of the human brain. The concept of neurodiversity has been developed within identity models of disability and, as such, it is generally associated with the use of identity-first language (disabled people or autistic people), rather than person-first language (people with disabilities or people with autism). However, it also strives to take into account the variability of personal and contextual experiences of individuals, refusing to subscribe to dichotomies of dis/ability (Runswick-Cole, 2014). A quarter of the human population is estimated to be neurologically different (neurodivergent) to the majority (neurotypical) (Singer, 2017). Examples of forms of neurodivergence that have been defined with medical approaches and psychological theories are: autism, attention-deficit/hyperactivity disorder (ADHD), dyslexia, dyspraxia, epilepsy, obsessive-compulsive disorder, and others (Chapman, 2020; Sadia, 2020; Szulc *et al.*, 2021). Moreover, some forms of neurodivergence overlap, and neurodivergent people may not fit only one label. Neurodivergent people may have increased or decreased sensory processing compared to neurotypical people (Remington and Fairnie, 2017; Russell *et al.*, 2019; Van Hulle *et al.*, 2019). Hypersensitivity can lead to experience sensory overload, which occurs when the brain struggles to receive to sensory stimuli received at excessive rate and intensity (Sadia, 2020). As the nature of XR relies on sensory stimulation, it is crucial to pay attention to how it might affect neurodivergent people and aid developers to understand their needs, while developing more neurodivergent inclusive XR technologies.

Most existing literature on the use of XR involving people with different learning and/or cognitive styles focuses on the positive aspects of utilizing these technologies for therapeutic purposes (Boyd *et al.*, 2018; Freeman *et al.*, 2017). However, there is little research on the experiences of neurodivergent people using mainstream XR technologies, for instance during gaming, and the challenges they might encounter when interacting with these technologies (Spiel and Gerling, 2021).

Related work

This work builds on previous research exploring sensory stimulation in XR technologies, sensory processing and neurodivergence.

XR and sensory stimulation

XR can be defined as an umbrella term that encompasses a range of immersive technologies, such as VR, AR and MR, that blur the lines between real and simulated worlds (Alizadehsalehi *et al.*, 2020). VR leverages computerized technologies to create a simulated 3D environment that is highly visual, immersive, and interactive (Slater and Sanchez-Vives, 2016) . On the other hand, AR relies on the overlapping of virtual objects enriching the canvas of the real world (van Krevelen and Poelman, 2015). Finally, MR is a combination of the two which often lacks a unified definition (Speicher *et al.*, 2019). Cognitive immersion is a pivotal aspect that influences our ability to experience the overlapping between these multiple worlds. To promote cognitive immersion, XR developers leverage their knowledge of perceptual systems (i.e. how individual interpret, respond and react to different stimuli) to create vivid XR experiences (Harris *et al.*, 2019; Latoschik and Wienrich, 2021). To better persuade the brain to accept the simulated world as authentic, developers match the stimuli with the average expectations of what will happen as a response to a particular event. For example, by changing the field of view of a XR visor as the user moves their head (Sherman and Craig, 2003). Additionally, "*to generate alternate precepts*" and "*novel 3D interactions*", developers also employ techniques that rely on the application of contrasting stimuli to different senses, such purposefully creating inconsistences between touch and vision either spatially or temporally (Lécuyer, 2017). The use of these techniques creates new types of effects: "*pseudo-haptic effects, self-motion sensations, and body-ownership illusions*" (Lécuyer, 2017).

Based on existing data about proprioceptive accuracy, which mostly relies on vision, developers integrate cross-modal perception for orientation, object identification, localization, and body motion (Sherman and Craig, 2003; Valori *et al.*, 2020). Furthermore, the relationship between visual experiences and different brain regions associated to other senses, such as hearing or touch, plays a crucial role in interaction with XR (Raybourn *et al.*, 2019; Sherman and Craig, 2003). As a result, all senses play a specific function in creating an illusion of presence in virtual and augmented environments.

Sensory processing and neurodivergence

Neurodivergent people process sensory stimuli in a way that is significantly different from neurotypical people (Alper, 2018; Morgan, 2019). For instance, autistic individuals can experience an auditory advantage (Remington and Fairnie, 2017), and miss subtle emotional cues in real and visually represented faces (Zolyomi and Snyder, 2021). Individuals with ADHD can either have difficulty reacting quickly to weak stimuli or respond quickly to them. Moreover, they can become bored in low stimuli environments (Kamath *et al.*, 2020). Speech recognition is an effortful task for people with dyslexia, thus integrating an acoustic signal with language while performing another task can be extremely challeniging (Derawi *et al.*, 2022). Individuals with dyslexia also have a reduced sensitivity to visual information over space and time (Manning *et al.*, 2022).

When an environment, physical and or digital, produces excessive stimulation, this could lead to unpleasant and even painful experiences of sensory overload. Sensory overload can trigger both physical and behavioural responses that include increase in heart rate and blood pressure, anxiety, and mental distress (Sadia, 2020). Therefore, it is crucial to acknowledge that it is common for neurodivergent people to have increased or decreased sensory responses (Sadia, 2020).

Existing literature on neurodivergence and XR focuses on the benefits of these technologies, specifically for health management and education purposes (Boyd *et al.*, 2018; Bradley and Newbutt, 2018; Thomsen and Adjorlu, 2021). A recent example is the opinion piece by Newbutt et al 2020, which outlines how the use of VR and other immersive technologies could support autistic with education, employment, and anxiety management in light of the difficulties that have emerged as a result of the COVID-19 pandemic (Newbutt *et al.*, 2020). However, amongst the available evidence, there are gaps in the understanding of the experiences of neurodivergent people when using XR technologies for personal interest (Alper, 2018; Spiel and Gerling, 2021). One exception is the study by Newbutt *et al.*, 2016, which looked at the experience of autistic adults when using a head-mounted-display (HMD) and interacting with a virtual environment. However, the two VR scenarios explored by participants were relatively short, 10 and 25 minutes respectively, and the study only investigated these experiences as part of a lab-based study rather than in everyday life. The scoping review by Savickaite *et al.*, 2022 on VR applications in autism research also points out to gaps concerning age, gender and geographical representation of autistic participants. The review highlights how with most existing studies involve individuals who are young, male, and North American or European. Furthermore, the review highlighted how the different definitions of VR across multiple studies can make comparisons and aggregation of findings a challenge.

Most existing literature on neurodivergence and XR is also primarily focused on individuals with autism, with little consideration for other groups of neurodivergent people who might have significantly different sensory processing patterns (Brosnan *et al.*, 2017). More recently, the study by Savickaite, McNaughton, *et al.*, 2022 has shown how autistic individuals and individuals with ADHD have significantly different visuospatial processes during complex VR drawing tasks. This highlights the importance of understanding different perceptual experiences of neurodivergent people. Ultimately, existing research does not provide a comprehensive understanding of the challenges that neurodivergent people face when using mainstream XR technologies, and it is crucial to explore this area and open the avenue for further discussions. In particular, studies are needed to understand the needs, preferences, and requirements of neurodivergent individuals for more inclusive XR environments, and find better ways to integrate them into existing development practices.

Aiming to understand how the XR accessibility challenges of neurodivergent people are addressed, we conducted two studies, a survey and a series of semi-structured interviews with two groups of participants, XR interested neurodivergent people and a group of XR developers. We explored the potential areas where these technologies fail to be accessible for neurodivergent users and the role of XR developers in addressing these accessibility areas. XR developers were involved to assess the level of awareness about XR accessibility concerns and learn how accessibility questions are considered during the XR projects development process. We further contribute with recommendations for ways to help neurodivergent users to adapt XR experiences by considering sensory processing and propose strategies to bridge some of the communication gaps between neurodivergent XR users and developers.

Methods

We hypothesized that individuals who are neurodivergent face and are concerned about facing sensory challenges and other barriers when accessing XR technologies. Moreover, we hypothesized that XR developers are largely unaware of the needs of neurodivergent users, which consequently prevents them from creating inclusive XR experiences. To test these hypotheses, we conducted a survey within neurodivergent communities and a semi-structured interviews involving neurodivergent individuals interested in XR technologies, and XR developers. To avoid the discussion of neurodiversity using a medicalized and often discriminatory approach, we didn't ask participants to specify their neurodiversity category, or have a clinical diagnosis to be able to participate. Individuals were invited to take part in the research if they self-identified as neurodivergent. As the purpose of the research was to understand the self-reported experience of neurodivergent individuals when using XR technologies in their daily life, the potential reasons for nonuse of XR technologies, and gain knowledge about the accessibility practice of XR developers, we selected questionnaires and semi-structured interviews as methods of choice. This was in line with the methodological approach used by other HCI studies investigating how neurodivergent users interact with different technologies (Das *et al.*, 2021; Hedges *et al.*, 2018; Szulc *et al.*, 2021). Due to Covid-19 regulations and restrictions being in place at the time of the study, both surveys and semi-structured interviews were conducted online. The study was granted ethical approval by the XXXX Research Ethics Committee.

Survey

Participants

A total of 15 individuals completed the survey. However, one response was incomplete and two were from participants who did not identify as neurodivergent, these were consequently excluded from analysis. The average age of the 12 included respondents was 36 ± 10.9 years. Ten participants were based in the UK, one in the USA and one in France. Three participants were students and the nine were employed. Of the 12 respondents, only five had previous experience using XR technologies and eight stated that they had faced significant barriers accessing or using XR technologies.

Procedures

The aim of the survey was to test the hypothesis that neurodivergent people experience barriers accessing and using XR technologies and to recognize specific areas of interest to inform the subsequent studies. The survey was advertised through social media (using relevant hashtags such as #ActuallyAutistic #ActuallyADHD #NeurodiverseSquad #ADHD), and through mailing lists and forums relevant to neurodivergent communities (including Neurodiversity subreddit, closed Autistic Girls Facebook group) and XR developers (including XR access and Triangles). Following the brief about the research goals, potential participants were asked if they self-identified as neurodivergent and asked for consent to take part in the study. Only people who self-identified as neurodivergent were able to take part in the survey. To ensure that participants understood the meaning of specific terms (Neurodivergent, XR, VR, AR and MR), the survey featured links to the third-party websites with lay language explainations. Specifically, for neurodivergence self-identification purposes we provided the link to the individual profilers developed by Do-IT Solutions, the global market leader in neurodiversity screening and assessment tools (https://doitprofiler.com/personal-profilers/). Conversely to provide clear definitions for the different types of XR technologies, we supplied the link with the explanation provided by the Franklin Institute, one of the oldest public education and science outreach institutions in the US (https://www.fi.edu/difference-between-ar-vr-and-mr). The survey was conducted remotely using RedCap, a dedicated tool with high standard for data protection that complied with the ethical guidelines for the project.

Throughout the survey, participants were asked about any prior XR experiences or any barriers accessing XR technologies, the context of current or potential usage, and to assess their overall experience of accessing XR technologies. At the end of the survey, participants were invited to participate in an interview to discuss their thoughts and opinions in-depth. Only participants indicating willingness to be interviewed were asked for their contact details.

Measures

The survey involved a mixture of quantitative and qualitative questions, including single and multiple-choice (usage and preference statuses) questions, as well as a few fill-ins and Likert-scale (sensory barriers related) questions. Quantitative survey responses were exported and analysed using descriptive statistics in Excel. Open-ended questions were manually coded using an inductive approach and grouped into themes using thematic analysis (Braun and Clarke, 2006).

Semi-structured interviews

Participants

Four neurodivergent participants (NP) were interviewed, two had previous experience of VR use and two who were interested in XR technology but had never used it before, all four participants described themselves as interested in gaming. Four XR developers (DP) were interviewed, three worked on VR technologies and one on AR technologies.

Procedures

The script for the semi-structured interviews with both neurodivergent participants and XR developers were designed according to the insights gathered from the survey. Interview scripts considered three scenarios: participants who had XR experience and did not encounter barriers, participants who had XR experience but did not encounter barriers, participants without XR experience. Prior to each interview, participants were asked to sign an online consent form made using the RedCap platform. Interviews with neurodivergent participants explored their XR accessibility needs and preferences, previous XR accessibility experiences and/or expectations, and their visions and opinions about the future of XR technologies in relation to neurodiversity.

Conversely, interviews with XR developers focused on understanding their knowledge of accessibility, if and how they consider accessibility needs and requirements during the project development, how decisions were made and what could help them design and develop more accessible XR experiences for neurodivergent users. Developers were recruited through relevant communities (including XR access) and LinkedIn posts without considering their experience in addressing accessibility requirements and needs, or the industry they worked in. The length of the interviews varied between 45 and 60 minutes.

Measures

Interviews were audio-recorded and transcribed verbatim. Transcripts were analysed inductively using thematic analysis to elicit emergent themes (Braun and Clarke, 2006).

Results

Survey results

Barriers described by participants were grouped in one of three categories, namely technical, financial and sensory, with a certain degree of overlapping between the three (Figure 1). Participants reported having used a number of different types of headsets for virtual and augmented reality primarily Oculus quest (3 participants), PlayStation VR set (2 participants), cardboard headset (1 participant), North Star (1participant), Valve Index (1 participant). Financial barriers were mainly linked to the high cost of XR technologies, in particularly VR visors, which were seen as an excessive expense for a technology that participants felt they might not enjoy and had still limited use in everyday life (4 participants). Sensory barriers were primarily cited in relation to VR use, compared to AR. Sensory barriers manifested as severe motion sickness (4 participants), overwhelming auditory stimuli (1 participant), dizziness (1 participant), nausea (1 participant), exhaustion (1 participant), and headache (1 participant). Other sensory barriers reported by participants were linked to difficulties with spatial awareness (1 participant). A technical barrier reported was poorly calibrated hardware (3 participants). Another participant felt that negative sensory experiences were more likely to occur when using low-quality hardware.

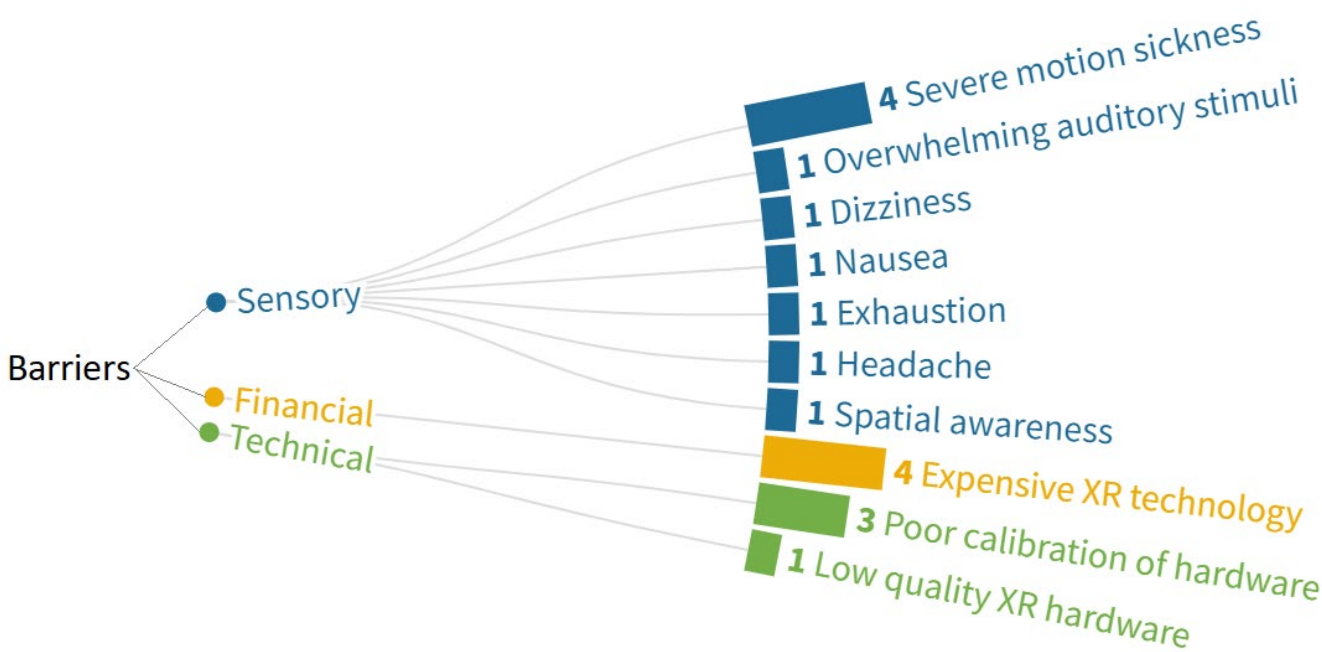

Figure 1 Overview of sensory, technical and financial barriers reported by survey participants

"I *get incredibly motion sick when experiencing VR unless it's a very low-motion game. It's an awesome experience but I cannot use it for very long before feeling too ill*"– Participant 10

"*I have difficulty choosing the right hardware that would be compatible with software or other hardware I own. [I feel] Worry about getting headaches or motion sickness from poorly calibrated or low-quality hardware*"– Participant 12

Overall, five participants stated that they still used XR technologies, albeit mostly occasionally, and three participants reported being interested in being able to use XR technologies in the future, particularly in the context of gaming as they imagined "*how interesting games could be*" (P6) thanks to more immersive experiences.

Semi-structured interviews results

As the structure of the interviews between the two groups were different, we separate the insights derived from interviews with neurodivergent users and XR developers.

Neurodivergent users

Neurodivergent users described experiencing sensory overload and shared the coping mechanisms they had developed as a result. Neurodivergent participants also described limitations related to the calibration and customization of XR technology and added recommendations for improving, or preventing such limitations.

Sensory overload and coping mechanisms

Both neurodivergent users who had experience using VR stated that they were frequently affected by motion sickness due to the delay between their movements and the response of the VR scene. Both participants tried to cope with motion sickness by minimizing or totally avoiding head movements while interacting in the VR world. However, despite their best efforts, discomfort still occurred leading them to avoid XR experiences involving excessive explorations and teleportation scenarios.

Generally, participants felt exhausted and overwhelmed "*very quickly*" (NP2) when "*too much*" (NP4) sensory stimuli were being delivered at once. Participants specified that this might be caused by the absence of the separation between the VR world and the user as the set is 360˚, and the interaction with multiple sensory stimuli is constant. Examples of triggering events were frequently swapping between characters, being bombarded by several sound effects at once, or interacting in scenarios featuring flashlights and high brightness. Finally participants found triggering the constant movement of decorative user interface details of the environment. On rare occasions, both participants reported that they could be in the VR world without experiencing sensory challenges for maximum of two hours. However, as a rule, most open-world VR experiences would include walking around and teleportation, which would provoke motions sickness and dizziness within 10-15 minutes. Discussing other negative XR experiences related to sensory processing, one of the participants (NP4) pointed out that their overall wellbeing could impact the virtual experience. For instance, feeling anxious during the day could enhance the overwhelming feelings generated by sensory stimulation leading to even quicker negative responses.

Unfortunately, neither NP2 or NP4 found any effective coping mechanisms that would allow them to continue interacting with the XR world, with the only solution available being to "get out" (NP4) of the XR world entirely.

Calibration and customization

Participants also reported difficulty finding hardware that could be calibrated to their preferences and customized to their needs, to help them avoid or minimize negative sensory experiences. According NP4, a poorly individually calibrated headset was "*irritating*" and could completely deteriorate the XR experience. Participants felt that enabling the customization of the sensory settings of XR experiences could improve the vast majority of sensory barriers they faced. For instance, NP1 found appealing the idea of being able to control the appearance or intensity of floating particles, flashlights, multiple sounds, or frequently swapping events. Additionally, NP3 stated that they would appreciate the ability to limit the number of sounds by turning off background sounds or enabling transcriptions instead of dialogues to improve the XR accessibility.

In addition, to avoid motion sickness caused by head movements, NP1 and NP4 suggested that an eye-tracking system could represent a potential solution. A better strategy for headset calibration was described as one of the most sought-after problems, NP1 stated that "*the ergonomic improvement of the hardware*" could significantly mitigate sensory challenges. Additionally, all participants stated that they often lost track of time when playing games (XR and non-XR). Thus, allowing users to set reminders to take a break could help them manage their sensory stimulation.

XR developers

XR developers showed lack of awareness of what accessibility for neurodivergent individuals could look like. Developers who had basic accessibility understanding did not know how to implement accessibility in the XR design process, unless this was explicitly required by a project plan or an individual customization request. XR developers acknowledged the need for accessibility resources specific to neurodivergence.

Lack of awareness and guidelines for accessibility implementation

Although all four developers showed interest in discussing XR accessibility, only one (DP1) stated that they were aware about accessibility needs linked to XR technologies use. Despite having a broad awareness of the topic, DP1 still felt that there was a lot confusion amongst developers in prioritizing which accessibility needs to address, if there are no specific project requirements. Furthermore, all developers complained of being confused by which questions should be asked to define accessibility needs, and understanding how accessibility modification should be incorporated into the flow of a project.

Even though all developers stated that they considered different elements of user experience which could be linked to typical accessibility during the project development, such as close captioning (DP3) or button size (DP2), none of the developers were aware of neurodivergence relevant needs ("*I don't actually know what makes difference to those [neurodivergent] users*" - DP2).

Limited user contact and desire for specific resources

None of the developers had worked in a team specifically responsible for implementing accessibility requirements before the taking part in the interview. Based on their own experiences, there were only two ways in which accessibility had been integrated in existing processes. The first one was a top-down approach directed by the project lead who would decide whether accessibility was a priority at each specific phase. The other approach was largely regulatory and will be linked to the compliance with standards for the software that were "*very much defined by the platform*" (DP3).

All developers stated that, in most cases, the needs and requirements of users with disabilities were incorporated in their projects only if there was an explicit request from the customer. Otherwise, as most projects are being "*pushed through time*" (DP1) due to the fast-paced nature software development (especially in start-ups), accessibility needs were overlooked (DP1). Most developers reported no previous direct engagement with users with disabilities and were thus unaware of how to improve XR experiences for and with them.

Developers stated that they frequently used knowledge-sharing platforms as a main source for "how-to" information. Along with social platforms, official guidelines from leading companies and other developers (such as official Oculus documentation and GitHub repositories) were listed as key sources of information (DP1, DP2). Additionally, they "*get inspired*" (DP3) by previous works from market leaders. Finally, developers felt that having access to resources where they "*can find and access information*" (DP1) about accessibility needs relevant to neurodivergence, and have a "*collective conversation and share resource collection for developers*" (DP2) were desirable and could go a long way into ensuring the integration of accessibility into XR development.

Discussion

This paper contributes to the existing literature examining the sensory processing experiences of neurodivergent individuals in relation to XR use, integrating a unique investigation into the design practices of XR developers. This study highlights the key challenges faced by neurodivergent individuals when interacting with XR technologies. Predominantly, these barriers are related to the excessive sensory stimuli of the XR worlds. In particular visual and auditory stimuli or motion delays could cause severe motion sickness, dizziness, and headaches. Participants had not found any satisfactory coping mechanisms to mitigate these negative experiences, and limiting their interactions with XR appeared to be the only viable strategy.

Some of the challenges that neurodivergent participants described during both survey and interviews were similar to the ones previously reported by neurotypical XR users. For instance, motion sickness linked to hardware characteristics, visual content in the virtual world, or interaction modalities (Li *et al.*, 2020).However, as highlighted in the study by Das *et al.*, 2021, compound effects on neurodivergent users are likely to be different from the ones experienced by neurotypical users due to increased sensitivity to inducing factors. Additionally, previous research has investigated how neurotypical users could mitigate motion sickness in VR, such as through the physical hand-eye-coordination tasks, real-world natural decay and adding visual effects or elements (Dennison and Krum, 2019; Jasper *et al.*, 2020; Tian *et al.*, 2022). However, no study tested the efficacy of these techniques for neurodivergent users.

Enabling access to customization settings within XR experiences would likely represent an effective solution to ensure that users can change the configuration of the system in a way that will work best for their individual sensory processing experiences (O Connor *et al.*, 2020). Neurodivergent participants in our study, reported that they would like to have control over their XR experiences, including being able to regulate the speed of movements or the appearance and intensity of decorative elements of the virtual environment. One example of how this has been successfully achieved is the game "The Last of Us 2", which features more than 60 accessibility settings and has been recognized as a gold-standard example of accessibility by numerous communities (Mészáros, 2021). Providing the freedom of customization of settings according to the unique variety of one's needs, instead of trying to solve a specific set of issues, seems the promising approach of making the XR more accessible for neurodivergent users, as well as the entire gaming community.

To ensure that XR technologies can become more accessible to neurodivergent users, it is essential to raise awareness about their needs amongst developers and promote better ways of communicating between the two groups. As stated by Das *et al.*, 2021, "*access does not reside in the specific features of a technology but instead is created through interaction between people and technology in particular contexts and at particular moments in time*". Thus, the key to accessible design of XR experiences lays in collective conversations that "*get people involved in design process*" (DP4) and promote sharing knowledge about the needs of neurodivergent users and their importance (Parsons *et al.*, 2017). These findings align with the broader calls for increasing Participatory Action Research in the context of autism and neurodivergence to promote agency and ensure that research conducted in academia and industry matches the priorities of neurodivergent communities (Chown *et al.*, 2017; Costley *et al.*, 2022).

The insights provided by developers highlight how the lack of awareness is deeply linked to the lack of resources supporting efforts towards better accessibility. Fast-paced projects require an instant understanding of what can be done and how it can be done. Otherwise, even with increased awareness of access needs, accessibility questions end up being ignored because "*there is only a limited amount of things you can do in order to [...] help with the accessibility aspect*" (DP2). Hence, knowledge sharing within the XR community is an integral part of managing the diversity of users' concerns (Al-Mashhadani and Ahmad, 2018; Wei *et al.*, 2015). Furthermore, developers need to be supported by organizational structures in the XR design industry that makes accessibility a key step in the design process rather than "*extra work to do*". Many of these challenges resonate with the difficulties expressed by academic researchers in the study by Pickard *et al.*, 2022, suggesting that systemic change is needed in industry as well as academia to honour the commitment of participatory research and design practices with neurodivergent users and other marginalised communities.

The findings of this study indicate that there is the need to increase the agency of neurodivergent XR users in managing settings that affect their sensory sensitivity experiences. There is also the need to support XR designers that are keen to design with accessibility in mind. These two needs, if met, are likely to also benefit neurotypical XR users and designers. With the premise that it is a social responsibility to include people with disabilities in computing, it is imperative that neurodivergent individuals are included in shaping increasingly popular XR technologies.

The small sample size of the study of both survey and semi-structured interviews limits the generalization of findings. Moreover, future comparative studies involving both neurodivergent and non-neurodivergent users could significantly help to understand the degree of overlap and the difference between the sensory barriers experienced by various groups of users, supporting the goal to develop more universally inclusive XR technologies. Finally, larger studies might help to unravel the details of specific sensory barriers hindering the use of XR amongst neurodivergent users, and the accessibility strategies that could be implemented by XR designers. Nevertheless, the alignment of the findings from this study with previous literature on XR and other domains of technology suggests that these results are likely to hold true in further research.

Conclusions

The XR accessibility needs and preferences of neurodivergent people have been, to date, under-researched. This study contributes a deeper understanding of the sensory processing challenges that neurodivergent users face when interacting with mainstream XR technologies. We have also contributed by highlighting how the lack of neurodivergence accessible features in XR technology has a systematic and organizational origin, where traditional processes do not consider accessibility an essential component of XR design. We hope that this contribution motivates the development of more neurodivergence accessible XR experiences. Within this context, the participation of both the neurodivergent community and XR developers in future research is essential to raise awareness of existing problems and discuss sustainable mechanisms to solve them. A concrete future step will be to create platforms for communication and knowledge sharing allowing for direct connections between neurodivergent users and developers promoting dynamic integration of accessibility in XR.

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Appendix

Screenshots to a part of a survey VR/AR Accessibility for Neurodivergent Users

Confidential

Page 2

In which country are you routinely based?	__________________________
Do you have access to Virtual Reality (VR), Augmented Reality (AR) or Mixed Reality (MR) technologies at home, work or any other setting? Click here to learn more about the difference between VR, AR and MR.	◯ Yes ◯ No
Do you have experience using one of these technologies? Pick all that apply.	☐ VR ☐ AR ☐ MR ☐ All of the above ☐ None
Can you specify what is the reason for that choice?	__________________________
Did you experience any barriers accessing VR, AR or MR technologies?	◯ Yes ◯ No
Did you experience any barriers to accessing VR technologies?	◯ Yes ◯ No
Did you experience any barriers to accessing AR technologies?	◯ Yes ◯ No
Did you experience any barriers to accessing MR technologies?	◯ Yes ◯ No
Can you specify what are these barriers?	__________________________
Would you like to try VR, AR or MR technologies regardless of what you said before?	◯ Yes ◯ No
How would you rate your experience of using VR technologies?	1 ―――――――――― 10 *(Place a mark on the scale above)*
How would you rate your experience using AR technologies?	1 ―――――――――― 10 *(Place a mark on the scale above)*
How would you rate your experience using MR technologies?	1 ―――――――――― 10 *(Place a mark on the scale above)*
How would you rate your experience using VR, AR and MR technologies?	1 ―――――――――― 10 *(Place a mark on the scale above)*

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Can you specify what is the reason for that choice?	__________________________
Are you currently using VR technologies?	◯ Yes ◯ No
Are you currently using AR technologies?	◯ Yes ◯ No
Are you currently using MR technologies?	◯ Yes ◯ No
Are you currently using any of these technologies (VR, AR or MR)?	◯ Yes ◯ No
Would you like to use VR, AR or MR technologies in the future?	◯ Yes ◯ No
Can you specify what is the reason for that choice?	__________________________
In what context have you tried/used VR, AR or MR technologies?	☐ Home ☐ Work ☐ Sessions with a therapist ☐ Other (specify): _____
In what context have you tried/used VR technologies?	☐ Home ☐ Work ☐ Sessions with a therapist ☐ Other (specify): _____
In what context have you tried/used AR technologies?	☐ Home ☐ Work ☐ Sessions with a therapist ☐ Other (specify): _____
In what context have you tried/used MR technologies?	☐ Home ☐ Work ☐ Sessions with a therapist ☐ Other (specify): _____
For what purpose you have tried/used VR, AR or MR technologies?	☐ Leisure ☐ Therapeutic ☐ Educational ☐ Professional ☐ Other (specify): _____
For what purpose you have tried/used VR technologies?	☐ Leisure ☐ Therapeutic ☐ Educational ☐ Professional ☐ Other (specify): _____

Examples of some questions for neurodivergent participants

Have you ever used VR/AR/MR?

- Which of these technologies have you used?
  - Why these technologies?
- When did you start using it?
- What have you used it for?
- How often have you used it?
- Where have you used it?
- Do you still use it?
  - Why not?

Which hardware/devices have you used/tried?

- What do you like about it?
- did you experience any barriers using this tech?
- what kind of barriers?
- Have you tried to mitigate them or adapt to them?

What did you use it for (gaming, therapy, education, etc.)?

- What type of games?
- Name the game?
- What type of activities are in the game?
- Did you experience barriers playing this game?
- What kind of barriers?
- What exactly provokes them?
- How soon they appear after starting to play etc.
- Are they persistent?
- Is there anything that help to mitigate them?
- What you did when you experienced them?
- Have you tried again?
  - if yes, does the problem reappeared?
- What would you change to improve your experience?

Example of some questions for XR developers

- Where does the accessibility sits in your work process?
- At what stage of the project, you/team consider accessibility questions?
- Is there anyone responsible for accessibility questions?
- Do you have any experience in working towards any accessibility NEED?
- How are accessibility issues/needs identified in your team?
- Do you have any experience in solving any accessibility issue?
- Does your accessibility work directly involve people with disabilities?
- What is the accessibility needs that you are solving most of the time? / Are there accessibility issues that you address in every project?
    a. Why this/these issues?
    b. How do you find them out?
    c. Do you address them in all projects?
    d. Why?
- Do you conduct accessibility tests?
    a. What happens if you identify accessibility issues?
    b. Do you solve them?
    c. To what extent?
    d. Who decides if the issues can or cannot be resolved at the current project?
    e. What can influence these people to decide in favour of resolving the issue?
- Are there any specific areas of accessibility your teams are interested in?
    a. Why?
    b. What influence these interest/prioritizations?
    c. What are you doing to address them? / What have you already done?
    d. What is the result?
- How do you evaluate the customer experience?
    a. Do you research the customer's accessibility experience?
    b. How do you decide which identified issues/needs should be addressed?
    c. What accessibility problem/need do you usually face in your work?
- Do you use any guidance on accessibility?
- What would you like to have to help you address accessibility issues? /How do you think the development process of XR technology in your team could be more inclusive? What resources and strategies would be helpful?
- Is there anything you would like to add over things we have discussed?
- Do you know neurodivergent who you think I should talk to?