Abstract

While Extended Reality (XR) autism research, ranging from Augmented to Virtual Reality, focuses on socio-emotional abilities and autistic children requiring low support, common interventions address the entire spectrum and focus on other abilities, including perceptual abilities. Based on these observations, this paper first addresses common practitioners' interventions, and then suggests XR use cases and guidelines to better support them. To do so, 34 interviews were conducted with stakeholders, mainly including practitioners, and then analyzed. Emerging XR use cases were compared with the findings from two former systematic literature reviews, and emerging design guidelines were compared with the findings from a literature survey that we conducted. Findings suggest that collaborative XR sensory-based and mediation approaches could benefit the entire spectrum.

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition with a worldwide prevalence of around one percent (Lord et al., 2020), and three main features (American Psychiatric Association, 2013): social communication and social interaction disorders, focused interests, and sensory modulation disorders. In particular, sensory disorders affect around 90% of autistic people[1] over the different sensory channels (Robertson and Baron-Cohen, 2017). Autistic traits include a tendency to focus on the details rather than on the overall situation (Frith, 1989), a perception that the world is going too fast (Gepner, 2018), executive dysfunction with for instance a resistance to change (Lord et al., 2020), and an associative thinking requiring to compare past experiences in order to make sense of a situation (Grandin, 2009). Co-occurring conditions are also common, e.g, attention disorders (Lord et al., 2020). Since autistic people belong to a spectrum, they display various sensorimotor and cognitive abilities, some requiring substantial support, being non-verbal and with cognitive disabilities, while others require "minimal support to complete academic work" (Bottema-Beutel et al. 2021, p.3).

While early, structured, and individualized approaches are advised to address autism challenges, multiple interventions exist (Sandbank et al., 2020). Behavioral interventions, such as Applied-Behavioral Analysis (ABA), focus on the child's behavior, including its antecedents and consequences, with many strategies, e.g., reinforcements (Lovaas, 1987). They can be combined with alternative communication methods, e.g., the Picture Exchange Communication System (PECS) (Flippin et al., 2010), or Makaton (Montoya and Bodart, 2009). Developmental interventions are grounded in developmental psychology and focus on active exploration and child-practitioner interactions (Piaget et al., 1969). Naturalistic Developmental Behavioral Interventions (NDBI) draw upon both previous interventions to teach developmental skills within naturalistic settings (Schreibman et al., 2015), e.g., the Early Start Denver Model (ESDM) (Rogers et al., 2012). Other interventions mainly focus on structuring the environment and self-monitoring, e.g., Treatment and Education of Autistic and related Communication-handicapped CHildren (TEACCH) (Mesibov et al., 2004). Psychodynamic interventions then focus on the social interactions and how thoughts affect behavior (Midgley et al., 2021). Sensory-based interventions also exist, to enhance the integration of multisensory interactive processes and cognitive abilities, such as with Sensory Integration Therapy (Schoen et al., 2018), or to prompt child-practitioner interactions through

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[1] This article uses autism stakeholders' preferences in terms of terminology, such as identity-first language (e.g., autistic people) (Bottema-Beutel et al. 2021).

multisensory spaces, such as with Snoezelen (Lancioni et al., 2002). At last, integrative interventions use elements from different interventions to best suit the child's needs (Klein and Kemper, 2016). Yet, interventions often present challenges, such as difficulties in terms of access, flexibility, hard-to-get training, or expensive cost (Griffith et al., 2012; Lang et al., 2010). This paper suggests using technology-based interventions to support them.

Technology-based interventions using video games on various mediums such as tablets, desktop computers, or robots, are promising to overcome these issues, as they often appeal to autistic children (Grynszpan et al., 2014; Mazurek et al., 2015). More specifically, recent reviews highlight that Virtual Reality (VR) (Bradley and Newbutt, 2018; Dechsling et al., 2021; Mesa-Gresa et al., 2018; Parsons and Cobb, 2011; Parsons et al., 2017) and Augmented Reality (AR) (Berenguer et al., 2020; Khowaja et al., 2020; Marto et al., 2019) are promising to complement autism interventions, through the creation of secure and individualized spaces, with a precise control over different stimuli, and the possibility to rehearse and record actions. Moreover, they display a good acceptability and usability with Head-Mounted Displays (HMDs) (Malihi et al., 2020; Newbutt et al., 2020) and room-centric spaces, e.g., Cave Automatic Virtual Environments (CAVE) (Cruz-Neira et al., 1992; Mesa-Gresa et al., 2018). In this paper, VR and AR are referred under the term Extended Reality (XR), because what belongs to the real and virtual worlds is a matter of proportions according to the virtuality continuum (Milgram and Kishino, 1994). Contrary to low-immersive devices (e.g., desktop computers), XR technology offers embodied multisensory capabilities which can be highly engaging for autistic individuals (Miller and Bugnariu, 2016). Although previous XR design reviews were conducted about autism interventions (Bozgeyikli et al., 2018), or more specifically NDBI (Dechsling et al., 2021), they seem to be disconnected from field practices that stakeholders encounter or use on a daily basis. Indeed, they are not informed by stakeholders' views, namely, the views from practitioners and autistic individuals. Hence, this paper aims at extending these previous reviews by adopting a participative design perspective mainly accounting for practitioners' views.

So far, most XR studies focus on socio-emotional abilities, as revealed by two systematic reviews (Berenguer et al., 2020; Mesa-Gresa et al., 2018). Indeed, even when some studies mention using XR as Assistive Technologies for autism interventions (Rosenfield et al., 2019; Syriopoulou-Delli and Stefani, 2021), they concern the training of socio-emotional abilities, and not XR technologies that could be added to support and enhance the daily life of autistic people. Thus, most studies exclude the individuals who cannot work on such skills, because these individuals already require substantial support for conducting daily tasks (Bozgeyikli et al., 2018). Yet, Parsons et al. (2019)'s findings from a two-year seminar including 240 stakeholders indicated that perceptual specificities have to be more considered during the design process to better support autism interventions. This involves using participative design to give all stakeholders a voice (Fletcher-Watson et al., 2019; Frauenberger et al., 2011; Parsons et al., 2019; Porayska-Pomsta et al., 2012). By using such a participative design approach and considering all stakeholders' concerns, this study aims at suggesting XR use cases to complement common interventions.

Moreover, most XR studies display inherent biases, due to possible misunderstandings or anxiety from autistic users, which prevent from their full validation (Bozgeyikli et al., 2018). They often come from a lack of communication between the different stakeholders involved (i.e., academics, practitioners, autistic individuals) (Pellicano et al., 2013, 2014), or from a non-consideration of autistic perception, non-ecological tests, or non-collaborative designs (Bozgeyikli et al., 2018; Parsons et al., 2019). Yet, apart from the recent Dechsling et al. (2021)'s study which extends NDBI to XR, no XR design recommendations are rooted in common interventions. Thus, a new set of XR user-centered design guidelines must be derived, informed by stakeholders' insights about common interventions, and by stakeholders' insights about XR guidelines in comparison with the existing XR autism literature. This paper aims at offering such guidelines.

The contributions of this paper are threefold. First, common practices of autism interventions are presented based on 34 semi-structured interviews with autism stakeholders, mainly including practitioners. Second, potential XR uses for autism interventions are derived from a comparison between the interviews' findings and the findings from two systematic reviews about XR autism interventions (Berenguer et al., 2020; Mesa-Gresa et al., 2018). Third, autism XR design guidelines are drawn from a comparison between the interviews' findings, and the findings from a literature survey that we conducted. After detailing the methods, results are presented following these three contributions. A discussion finally suggests future directions for the XR autism research field.

Methods

The first objective of this paper was to get insights about common autism interventions, to then derive XR use cases and guidelines that are close to stakeholders' needs. To that respect, semi-directed interviews were designed and conducted, following methods that are described in the next subsection. The second objective was to check whether stakeholders' insights about potential XR uses as a support for interventions, that were collected during the interviews, matched the focus of the existing XR studies. As two recent systematic literature reviews focusing on XR autism interventions existed at the time of our study (Berenguer et al., 2020; Mesa-Gresa et al., 2018), the interviews' findings were compared with the findings from these reviews. At last, this paper aimed at offering XR design guidelines drawing upon stakeholders' needs, as such guidelines were not provided by the two previous systematic reviews, nor by other reviews specifically focusing on XR autism design guidelines (Bozgeyikli et al., 2018; Dechsling et al., 2021). Thus, an XR literature design survey was conducted to look for these guidelines, and the interviews' findings were then compared with the survey's findings. The method used to conduct this survey is presented in the second subsection called "Method for the literature survey".

Method for the semi-directed interviews

Semi-directed interviews were conducted with French autism stakeholders, mainly including practitioners. After presenting the methodology, data analyses are exposed, both being summarized in Figure 1. [Figure 1 top]

Participants

To get in contact with autism stakeholders, personalized emails were sent to three Autism Resource Centers, 49 healthcare structures specialized in autism and neurodevelopmental disorders, three associations representing autistic individuals and relatives, and 66 practitioners. Most contacts were found in the TAMIS address list[2]. Moreover, proceedings of recent conferences about autism, sensoriality and technology were identified, using queries with the following keywords: "ASD" OR "autism", "digital" OR "technology", and "sensoriality". In Europe, sixteen conferences or workshops appeared, from 2012 to 2019, mainly in France, except for two in Spain and one in England. Every attendee's profile was examined and contacted when their activity simultaneously focused on autism, technology, and sensoriality. Furthermore, people interviewed were asked for other contacts at the end of each interview. Other experts were discovered through papers, blogs, and Autism Resource Centers' webpages. Only French participants were contacted to avoid language misunderstanding with the main author. Moreover, most participants were in the Ile de France area (i.e., Paris district), to facilitate further in-situ investigations, e.g., observations of medical practice.

Formal interviews were conducted with 34 stakeholders, including practitioners (n=29), people from the autism community (n=4), and academics (n=1). Table 1 summarizes their profiles, which tend to be representative of the distribution of all autism fields [Table 1]. Practitioners and academics are highly experienced, often with more

[2] The Tamis list details practitioners and associations specialized on autism in Ile de France - tamis-autisme.org/)

than ten years of practice (n=21). Practitioners have various backgrounds, i.e., public sector (n=10), private sector (n=5), or both (n=14). They mainly use NDBI (n=9), integrative (n=8), and sensory-based (n=7) interventions. Autistic individuals and their relatives favored NDBI (n=4), and often mentioned the ABA method. Technology-based interventions were often reported (n=23), and all autistic participants already used digital tools (n=4). All participants agreed to be contacted again for further questioning or future testing.

Protocol

Interviews had two objectives: first getting an overview of how autism interventions are conducted, and second gathering the potential needs and viewpoints of participants regarding the use of digital tools as a support for interventions, and particularly XR. Interviews were based on a semi-directed questionnaire targeting practitioners that was built in three phases as suggested by Lallemand and Gronier (2016): phase 1 - demographics (2 questions); phase 2 - interview body (30mn, 9 questions); and phase 3 – ending (5mn - 2 questions). The interview body is divided into two main parts targeting common autism interventions without digital tools from questions 3 to 9 (Q3 to Q9), and then with digital tools from Q10 to Q11. About the first part, Q3 to Q7 covered the main aspects of non-digital autism interventions. These questions were derived from the authors' knowledge at the beginning of the study, coming from a non-exhaustive review of the literature, including the French grey literature about intervention guidelines (Haute Autorité de Santé, 2018), as well as online communications from Autism Resource Centers. Then, Q8 targeted sensory-based interventions, to assess their relative importance among common practices. Q9 was added after the sixth interview, as all participants mentioned the use of mediation activities. Then, the second part investigated the current use and potential needs regarding digital tools (Q10) and XR (Q11). All questions were rephrased depending on the participant and on the context of the interview. Table 2 presents the basis of the questions in column 2, with respect to the three interview phases in column 1 [Table 2]. For each question, keywords being representative of related topics were used to ask for additional details when these topics were not spontaneously mentioned by the interviewee. The list of keywords was gradually extended and refined over time, as the authors gained insights about autism interventions, the final list being displayed in column 3. To elicit more insights over specific actions and practices, the critical incident technique (Flanagan, 1954) was used, i.e., participants were always asked to give precise examples of the elements they were speaking about, for instance by describing the last time when the element occurred. With autistic participants, non-appropriate question was removed (Q3), and two questions were added: QA1 assessed their viewpoints regarding the healthcare interventions that they experienced, and QA2 asked about their atypical sensory perception. With academic participants Q3 was removed, and technology-focused questions were more explored (Q10, Q11).

Interviews with autism experts last between 34' and 94' with a mean duration of 59'. They include 19 women and 11 men, and were conducted using phone (n=18), visio-conference (n=7), or face-to-face (n=5). With autistic individuals and/or their families, they last between 43' and 70', with a mean duration of 51', and were conducted using phone (n=3), or face-to-face (n=1). Two interviews were conducted with mothers of autistic children (one boy and one girl), one interview with an autistic man, and one interview with an autistic man and his family (the family being present due to his specific needs). Every participant signed a consent form prior interview, mentioning they were free to stop whenever they wanted. All interviews were audio recorded. All data collected were anonymized for transcription and analysis, using the "itw" keyword followed by the interview number. For security reasons, no online cloud system was used to store data, and transcriptions were made manually.

Data analysis

Data analysis mainly used a bottom-up approach with inductive coding called *grounded theory* (Charmaz, 2006). Hence, interview data was coded to extract meaningful phrasings, that were then sorted into different concepts and categories. The technique starts from no preconceived concepts. Instead, they are gradually built through multiple iterations between the data, concepts, and categories, which involves the use of constant comparative methods at the different analytic stages (Charmaz, 2006, p.54). The analysis process stops when the classification becomes stable. As concepts are sometimes connected, the same phrasing can be sorted into multiple concepts. During this qualitative analysis process, the first author' subjectivity could have influenced the findings. Thus, to limit potential biases, an objectivist approach was used, i.e., the analysis focused on the interview data for themselves, without considering how they were produced (Charmaz, 2006, p. 131). Hence, repetitions, hesitations, and prosody were not considered during the transcription process.

This overall grounded theory analysis includes three main steps. First, four main grounded theory iterations were conducted by the first author at different times (i.e., offset of several weeks) to reduce potential biases. Since all interviews were conducted in French, the concepts and categories were first created in French, and then translated and refined in English. To analyze interview data about non-digital interventions, only inductive coding was used. About data regarding digital tools and XR, inductive coding was first used, and then, from a late analytic stage, the emerging concepts were refined in connection with the XR autism literature to reveal potential gaps (Charmaz, 2006). This comparison process started at a late analytic stage to avoid importing too many pre-conceived ideas when starting the analysis. It involved the second and third steps of our overall analysis process. In the second step, participants' needs regarding XR uses were compared with the existing XR uses that were reported by two systematic reviews (Berenguer et al., 2020; Mesa-Gresa et al., 2018) (see results' section called "Comparison between stakeholders' needs and literature XR uses"). These reviews were selected as they were recent, systematic, and exhaustive regarding XR existing use cases, and thus allowed to derive objective percentages representing the relative significance of the different purposes of XR autism studies (e.g., social training). Thus, they were suitable to draw a comparison with our interviews' findings, and to reveal potential gaps. At last, during a third analytic step, since the two systematic reviews did not provide XR design guidelines accounting for stakeholders' needs, nor other reviews specifically focusing on XR autism design guidelines (Bozgeyikli et al., 2018; Dechsling et al., 2021), an XR autism literature survey was conducted in relation to our emerging grounded theory. The objective was to identify such guidelines that we could then compare with the interviews' findings (see results' section "Comparison between stakeholders' XR design insights and literature guidelines"). The method that was used to conduct this literature survey is described hereafter. The three overall analytic steps were here presented sequentially for enhanced clarity, but they were conducted in parallel during the late analytic stage.

Method for the literature survey

Method for the article selection from the literature

Drawing from Charmaz (2006, p.164-168)'s grounded theory method, we conducted an XR autism literature survey during the late analytic stage. The purpose was to derive literature design guidelines that we could compare with the interviews' findings. At this late analytic stage, major XR concepts about sensorimotor and mediation issues had emerged that were not expected when conducting the interviews. Hence, as the survey was informed by the state of the grounded theory, it focused more on XR sensorimotor and mediation issues. Moreover, the survey mainly considered participative design approaches to consider all stakeholders' views. Online queries were made with Google Scholar engine, to use the "cited by" option for each paper and thus reference more recent studies with similar interests. They combined the keywords: "Autism" OR "ASD", "Virtual Reality" OR "Virtual Environment" OR "Augmented Reality" OR "Mixed Reality" OR "Technology" OR "Digital Tool", "Multisensory Environment" OR "Sensoriality" OR "Mediation", and "Participative Design".

Two inclusion/exclusion criteria were used: (1) autism-related stereoscopic XR studies were included (e.g., CAVE and HMDs), or computer-related studies, if presenting relevant features for the XR medium (i.e., robot, touch-screen device, or room-centric setup); and (2) articles not offering design guidelines were excluded. Moreover, we focused more on participative design studies, as being more representative of all stakeholders' views.

Screening process and protocol for analysis

The first author searched the literature and reviewed all the studies according to the inclusion/exclusion criterions. The title was first screened. If relevant, the abstract was then screened, and followed by a full-text reading. If relevant, the study was then included in the survey. In total, 37 articles were selected (Alcorn et al., 2014; Aruanno et al., 2018; Bartoli et al., 2014; Bozgeyikli et al., 2018; Brosnan et al., 2019; Brown et al., 2016; Carlier et al., 2020; Constantin et al., 2017; Dautenhahn, 2000; Dechsling et al., 2021; Duris and Clément, 2018; Garzotto et al., 2017; Garzotto and Gelsomini, 2018; Halabi et al., 2017; Kerns et al., 2017; Koirala et al., 2019; Krishnappa Babu et al., 2018; Kuriakose and Lahiri, 2017; Lorenzo et al., 2019; Malihi et al., 2020; Maskey et al., 2019; Newbutt et al., 2016; Newbutt 2013; Pares et al., 2005; Parsons et al., 2019; Parsons et al., 2017; Robins et al., 2004; Spiel et al., 2017, 2019; Tang et al., 2019; Tarantino et al., 2019; Tardif et al., 2017; Tsikinas and Xinogalos, 2019; Virole, 2014; Wallace et al., 2010, 2017; Whyte et al., 2015). The selected articles were first screened for XR design guidelines, and then sorted according to the emerging concepts coming from the interview analysis. If a literature design guideline suited some emerging concept from the interviews, it was assigned to it. Else, if no relevant concept could be found, a new concept was created, and the guideline was assigned to it. In that case, the already assigned phrasings from the interviews and the literature design guidelines were double checked to see if they could also fit with this new concept. This refactoring process was also applied when concepts gradually changed during the analysis of the interviews.

Results

Stakeholders' insights about autism interventions without and with digital tools are first detailed, and respectively summarized in tables 3 and 4 [Table 3][Table 4]. Then, stakeholders' needs are compared with existing XR uses from autism research drawing from two literature reviews (Berenguer et al., 2020; Mesa-Gresa et al., 2018), the findings being summarized in table 5. Finally, stakeholders' design insights are compared with XR literature design guidelines, the findings being summarized in table 6. For all tables, concepts and categories are reported from the most to the least reported concept or category according to stakeholders. Throughout the article, the number X of participants mentioning each concept is written inside parenthesis (n=X), next to a literature reference if containing a related guideline. The categories' names are italicized. Participants' quotes were translated from French to English. The term "autistic child" is often employed, as participants mainly spoke about autistic children.

Analysis of common autism interventions

This subsection details common autism interventions according to stakeholders, first without and then with digital tools. For enhanced readability, and due to differences between methods' names in France and in other countries, methods' names are not mentioned, except when important for the overall understanding.

Common non-digital autism interventions

About the intervention context, *Individualize the intervention program* and *Structure the intervention program* largely appear (respectively n=33, n=27), as ritualization and strong interindividual differences are common. Individualization requires practitioners to be "creative", as a psychometrician says, depending on the intended therapeutic outcomes, i.e., starting from the child's interests (n=32) to tailor rewards (n=16) and games (n=10). For instance, a team supervisor says: "if a child loves the cartoon "Cars" then we'll use boxes with Cars!". Such creativity concerns long-term projects (n=13), the care methods used (n=6), and the sessions (n=14), as they always depend on the child's state (e.g., tired). Though, individualization remains challenging (n=15), being the most-reported sub-concept about difficulties faced in interventions, especially with non-verbal children who require substantial support. About structuration, at the session level, it consists in offering predictability (n=27), of time (n=21) and space (n=19), such as routines (n=17). For instance, a speech therapist always "sets the phone in the drawer to avoid unexpected ringing". This prevents children from getting over aroused due to unexpected stimuli. Yet, difficulties can also be activity-related (n=14), for instance since providing structured settings may be easier in public institutions. At the intervention program level, different periods of time with different activities are planned (n=11) which last from days to months, depending on children. Practitioners first observe children through free play (n=8), and then leverage their interests to strengthen the dyadic relationship through working activities (n=7). Yet, practitioners warn about not over-using structuration (n=6), as not preparing for real life (n=4).

Regarding the intervention process**,** most stakeholders advise to *Engage children in their intervention program* (n=33), to maximize the intended outcomes. This mainly relies on using playful activities (n=30), strengthening the therapeutic alliance (n=30) (i.e., child-practitioner relationship), and using behavioral strategies (n=26). Playful activities derive from developmental methods. The therapeutic alliance consists in building a secure dyadic relationship then allowing to perform challenging tasks. It involves working on the content, with individualized playful activities (n=27), as well as on the context, for instance by adapting the practitioner's behavior (n=19). As an occupational practitioner said: "I whisper, speak quiet, speak up, or speak with Makaton gestures". Behavioral strategies (n=26) mainly include using rewards (n=19) and gradually increasing challenges (n=18). Yet, building the therapeutic alliance remains difficult (n=9), especially with children requiring substantial support (n=9).

Work on sensoriality in intervention (n=26) largely appears due to widespread sensory disorders, with two main concepts, i.e., Work on Sensory Processing Disorders (n=21) and Provide multisensory environmental adaptations (n=20). Practitioners often use sensory habituation to train hypo/hyper sensitivities (n=15). To that respect, multisensory spaces allow "to first remove distressing elements and then to increase them" (n=2). Other practices consist in modulating the audio-visual speed (n=7), or in working on multisensory binding (n=5). Sensory adaptations aim at maximizing attention and engagement, with various techniques. For instance, sensory loads targeting the hyposensitive channels can be used to regulate the child sensorimotor balance (n=13), or sensory protections to protect the hypersensitive channels (n=12), such as protection headphones (n=12).

At last, it is necessary to *Assess the state of the individual over time* (n=29), on the long (n=28) and on the short terms (n=21). On the long term, evaluations are first conducted at the intervention start, by combining standardized tests about sensorimotor (n=21), and psycho-developmental features (n=18). These tests are mainly based on questionnaires, interviews with relatives and/or the child, and clinical observations (respectively n=9, n=5). Then, combining evaluations at regular time intervals (n=8) allows to infer the child's progress. On the short term, observations are used (n=18) by looking at specific individualized features, e.g., repetitive behaviors (n=2).

Existing uses of digital tools in interventions

According to most participants, digital tools can support common interventions (n=27), as they are engaging (n=2), predictable (n=2), individualizable (n=2), repeatable (n=2), responsive (n=1), stable (n=1), can relieve from human interaction (n=2), and can allow to be wrong (n=1) (see Table 4). Tablets are often used, being intuitive for children (n=4), as well as computers. Participant's interests go beyond social skills, and include three main categories, namely *Social skills* (n=13), *Assistive technologies* (n=13), and *Mediation/Well-being* (n=10), and three minor categories, namely *Education* (n=8), *Sensoriality* (n=8), and *Diagnosis* (n=2). Various games are used to adapt to the child's abilities, the intervention context, and the intended outcomes. Games with simple interfaces, little information, and clear goals are preferred (n=5). To train social skills, social scenarii (n=3) are often used with solo (n=4) or group (n=2) activities. Then, assistive technologies are highly individualized. For instance, a team supervisor mentions the case of a non-verbal autistic child, who knows all Disney cartoons by heart, and uses a tablet to select and play the sentences that she wants to say from them. About mediation/well-being purposes, any appealing game can be used (n=10). A psychometrician notes that "video games allow to get into a prismatic relationship between the screen, the therapist and the child". To minimize adverse effects due to over-exposition to screens (n=5), digital tools must be presented as other activities, such as drawing, and used within a controlled setting, i.e., with an adult and a time limit. Yet, many practitioners remain hostile to using them, as it may increase the distance to the child (n=3), or due to a phantasm to be replaced by machines (n=1).

Comparison between stakeholders' needs and literature XR uses

The findings from the comparison between the stakeholders' insights and the XR systematic reviews (Berenguer et al., 2020; Mesa-Gresa et al., 2018) are presented following four main categories which emerged from the analysis: *Mediation and Well-being* (n=16), *Social, Education and Cognitive Training* (n=14), *Sensoriality* (n=13), and *Assistive technologies* (n=5) (see Table 5) [Table 5].

Mediation and Well-being

Although most participants mention the *Mediation and Well-being* category (47%), it remains under-researched, only representing three percent of the studies in Mesa-Gresa et al. (2018)'s review. Though, Newbutt et al. (2020) previously raised this need, with 29 autistic children answering "It relaxes me and I feel calm" to the question "What could or would you use VR HMDs for?". Participants evoke two main concepts, i.e., Make the child available for performing challenging tasks (n=13), which considers ways to reach a secure state before performing them, and Support the therapeutic alliance through mediation activities (n=6). Three use cases appear. First, use cases draw upon multisensory spaces such as Snoezelen (n=8), to strengthen the therapeutic alliance through secure intermediate XR spaces. Second, use cases are tailored to real-life stereotypic behaviors that children need to use to calm down, e.g., being in a car (n=1). A team director describes them as "derivatives of stereotypies", to "fill some sensory needs in a less stigmatizing way". At last, creative scenarii appear, in line with common interventions (n=3), e.g., music-making (n=2). Yet, as some children may struggle to stop using these appealing environments (n=3), participants suggest to gradually decrease any appealing stimuli before to stop (n=1).

Social and Cognitive Training

Whereas 41% of the stakeholders mention the *Social and Cognitive Training* category, more than 87% of the studies from the two literature reviews are connected to it (Berenguer et al., 2020; Mesa-Gresa et al., 2018). Real-life use cases mostly appear, with two main concepts, i.e., Train socio-emotional & Interactional abilities (n=14) and Train cognitive abilities (n=6). The first concept consists in gradually habituating the child to daily social situations through a secure XR space. To that respect, task-dependent features can be modulated (e.g., number of people) in various aversive situations (n=12) (e.g., medical examinations (n=6)), to promote the generalization of the skills learned into real life. Then, cognitive abilities include daily living skills (n=4), at home (e.g., brushing teeth) or outside (e.g., buying things in a supermarket). Other cognitive skills are mentioned (n=3), such as attentional abilities (Escobedo et al., 2014), inspired from behavioral (e.g., ABA) (n=1) or educational approaches (e.g., Boehm-3) (n=1) (Boehm and Psychological Corporation, 2000). Yet, such scenarii would only benefit individuals requiring low support, being able to understand them. An autistic participant also stresses that "No manual could ever cover all possible situations". Indeed, a psychometrician reports the case of an autistic adult who had learned the "right" way to greet people and got lost at work due to the variety of situations encountered.

Sensoriality

Whereas participants highly mention the *Sensoriality* category (38%), including all psychometricians and occupational therapists, it remains under-explored in the literature. Indeed, only the *SEMI* project (Magrini et al., 2019) focuses on training motor skills, using a kinect camera and four distinct applications. Three main concepts appear, i.e., Rehabilitate sensory disorders (n=10), Assess sensory disorders (n=6), and Work on action-reaction principles (n=4). Two main use cases emerge from the interviews: gradually adding stimuli to reach the tolerance thresholds, and then conduct sensory habituation; or gradually removing stimuli from a multisensory scene to assess the tolerance thresholds. A psychometrician says: "the challenge is to recreate contexts for assessing the tolerance thresholds while conducting a therapy". Possible scenarii range from real-life (n=7) to multisensory (n=6) spaces, depending on practitioners' preferences and the child's abilities. For instance, they include a supermarket with adjustable stimuli (e.g., dimming the lights) or Snoezelen-like spaces. A psychologist stresses that working on sensory disorders allows to better include non-verbal individuals with cognitive impairments. At last, an occupational therapist warns about the impossibility to recreate the richness of real-life stimuli in XR.

Assistive Technologies

Although some participants mention the minor category *Assistive technologies* (15%), it is absent from the two literature reviews considered. Two main concepts appear: Provide context relevant-only information (n=4) and Support sensory strategies (n=1). The first one can be achieved by adding and/or removing contextual information, e.g., adding information about the emotions of people around (n=1), or filtering a distressing noise (n=1). The second one aims at making the child secure enough to then be able to perform challenging tasks. To that respect, a participant suggests creating a tipi-like space augmented with sounds and colors, inspired from a child who could enter a tipi-like space in his classroom when feeling overwhelmed to get resourced and then go back to his class.

Comparison between stakeholders' XR design insights and literature guidelines

This section draws design guidelines from the comparison between the interviews' findings and the literature (see table 6) [Table 6]. Its subsections follow the main categories that were derived from the grounded theory process.

Task design

Individualization is advised to cater for children and practitioners, regarding both the content (Bozgeyikli et al., 2018; Carlier et al., 2020; Dautenhahn, 2000; Dechsling et al., 2021; Parsons et al., 2019; Parsons et al., 2017; Tang et al., 2019; Tarantino et al., 2019; Whyte et al., 2015; n=15) (e.g., stimuli, tasks), and the medium (Dechsling et al., 2021; n=1). For instance, a psychometrician mentioned using video games as "modelling dough", i.e., by adjusting every possible parameter. Whereas participants mainly suggest displaying familiar XR content (n=14) (e.g., drawings), the literature focuses on adapting the way the environment works (e.g., number of stimuli), sometimes with physiologically informed platforms (Krishnappa Babu et al., 2018; Kuriakose and Lahiri, 2017).

As in common interventions**,** engagement aims at maximizing the intended outcomes. According to the participants and the literature, it requires to tailor the environmental motor and cognitive complexity to the child's abilities and to the intervention context (Bozgeyikli et al., 2018; Carlier et al., 2020; Dechsling et al., 2021; Tang et al., 2019; Tarantino et al., 2019; Whyte et al. 2015; n=13). It also relies on offering predictable and simplified audiovisual content to prompt discovery (Bozgeyikli et al., 2018; Carlier et al., 2020; Dautenhahn, 2000), including some unexpected events (Alcorn et al., 2014; Brown et al., 2016; Virole, 2014; n=3), to create a "slight strangeness", as a psychologist said. Using common NDBI principles is advised, i.e., rewards, imitation, and sense of agency. Rewards must be tailored to the performance (Constantin et al., 2017; Dechsling et al., 2021). About imitation, the practitioner may imitate the child, or conversely, with promising outcomes over the therapeutic alliance and the training (Dechsling et al. 2021; n=1). Supporting the sense of agency then consists in making the child active (Bozgeyikli et al., 2018; Dautenhahn, 2000; Parsons et al., 2019; Spiel et al., 2019; n=14), possibly with authoring activities (Bozgeyikli et al., 2018; Pares et al., 2005; Parsons et al., 2019; n=3), e.g., drawing upon the painting VR game *Tiltbrush* (Ying-Chun and Chwen-Liang 2018; n=2). All these features and other strategies (Bozgeyikli et al., 2018; Kerns et al., 2017; Tang et al., 2019; Tsikinas and Xinogalos, 2018; Whyte et al., 2015; n=5), such as using a scoring system (Bozgeyikli et al., 2018; Kerns et al., 2017) promote the child's fun.

Considering autism sensoriality and perception allows to create well-suited designs for children from the entire spectrum. To that respect, structuring the time and space is advised (Bozgeyikli et al., 2018; Carlier et al., 2020; Dautenhahn, 2000; n=8), e.g., using time timers and allowing to rehearse actions (Bozgeyikli et al., 2018; Carlier et al., 2020; Lorenzo et al., 2019; n=10). Due to sensorimotor disorders, accessible interactions are preferred, such as touchless interaction (Bozgeyikli et al., 2018; Brown et al., 2016; Parsons et al., 2019; n=4), as well as offering varied interaction possibilities (Bozgeyikli et al., 2018; Pares et al., 2005; Parsons et al., 2019). To move in space, embodied interaction is preferred over teleportation techniques (Bartoli et al., 2014; Bozgeyikli et al., 2016; Brown et al., 2016; n=1). Finally, drawing links with the real world is advised to make experiences meaningful, e.g., including familiar objects into XR (Bozgeyikli et al., 2018; Tang et al., 2019; n=1), and by considering autism perception during the design process, e.g., associative thinking (Dechsling et al., 2021; Virole, 2014, n=2).

Collaboration possibilities must be offered, as the child-practitioner relationship is at the core of interventions. Hence, practitioners have to be able to prompt children (Dechsling et al., 2021; Parsons et al., 2019; n=2), while children can see them in order to be reassured (Dautenhahn, 2000; n=10). Moreover, controls must be shared between them (n=10) so that the child can be active. Indeed, a psychometrician suggests that the impossibility in many VR applications to be with the patient decreases practitioners' acceptability. According to two participants, the practitioner must be visible only if context-relevant regarding the XR scenario, e.g., for medical examinations.

Protocol to conduct XR sessions

Stakeholders insist on creating a secure context to reduce potential biases, possibly due to participants' anxiety. Before and during sessions, it consists in offering predicability (Garzotto et al., 2017; n=5), making the experience meaningful (Dechsling et al., 2021; n=4), and supporting engagement (Bozgeyikli et al., 2018; n=8). In the long run, it relies on including the XR experiment as part of the overall intervention (Bozgeyikli et al., 2018; Robins et al., 2004; n=4), and/or on planning a free play period to get the child accustomed to the system (n=3).

Mixed methods (i.e., qualitative and quantitative methods) that are adapted to children's abilities may help to assess their experience. Although no consensus exists in the literature, and a comprehensive overview is beyond the scope of this paper, our analysis suggests major practices. Before sessions, clinical questionnaires may be used to assess developmental and sensorimotor abilities (Malihi et al., 2020; Maskey et al., 2019). A quantitative analysis of behavioral and physiological data before and during sessions may help to infer the child's state (Dechsling et al., 2021; Koirala et al., 2019; Kuriakose and Lahiri, 2017). Then, custom questionnaires, often self-report, are often used to assess engagement (Aruanno et al., 2018; Garzotto et al., 2017; Garzotto and Gelsomini, 2018; Tarantino et al., 2019), along with standardized XR questionnaires, e.g., targeting the feeling of presence (Wallace et al., 2010, 2017). Evaluations must consider the practitioner's impact over the child (Dechsling et al., 2021). Their comparisons at regular time intervals may yield insights about the child's evolution. Such evaluations can be combined with qualitative evaluations, i.e., observations (Brown et al., 2016; Pares et al., 2005; n=2), or interviews with practitioners, relatives, and the child if possible (Spiel et al., 2017; n=1). Yet, a psychiatrist says that assessing the intervention outcomes remains challenging, as "during the week the child does 300000 things".

Design process

Creating autism-friendly environments requires using participative design (Bozgeyikli et al., 2018; Brosnan et al., 2019; Parsons et al., 2019; Spiel et al., 2019; n=5), to consider all stakeholders' needs, including autistic individuals requiring substantial support (Bozgeyikli et al., 2018; Parsons et al., 2019; n=7). According to the participants and the literature, equipment choices must depend on: the healthcare context, e.g., being affordable (Parsons et al., 2019; n=2); the child's abilities, e.g., being resistive and non-tethered (Bozgeyikli et al., 2018; Dautenhahn, 2000; Newbutt et al., 2016; n=1) ; and the XR tasks (Dechsling et al., 2021), e.g., using AR to prompt the generalization of skills. Whereas four participants are reluctant about using HMD with autistic children, mainly due to risks of isolation (n=2), the other participants advocate for a controlled use, namely, with a practitioner. Yet, practitioners stress that the acceptability and usability may be child-dependent (n=9). Moreover, to not induce anxiety, wearing the HMD may require using sensory habituation beforehand (n=3), and conducting the experiment in the usual clinical setting of the child (Bozgeyikli et al., 2018; Parsons et al., 2019; n=1). At last, although manufacturers recommend using XR from the age of 13 (Gent 2016), participants advocate for using task-dependent recommendations, based on the child's abilities and the practitioner's expertise (n=7), e.g., 7/8 for sensory-based and relaxation purposes (n=2), and 10/13 otherwise (n=5).

Information presentation

Displaying little and clear information is advised due to autism filtering difficulties, i.e., only task-relevant stimuli (Bozgeyikli et al., 2018; Carlier et al., 2020; Virole, 2014), and audiovisual simplification (Bozgeyikli et al., 2018; Tarantino et al. 2019; n=4). Adapting to the child's pace may also support understanding, e.g., adjusting the information speed (Tardif et al., 2017; n=13). Indeed, as a psychometrician said, "learning requires slowness".

The level of details and the realism of the graphics must be task-dependent (n=7), e.g., realistic for social scenarii (n=5), and abstract and creative for mediation purposes (n=1). To that respect, a psychologist stressed that "realistic and non-realistic environments won't interest the same practitioners" (n=1). About social scenarii, adjustable collaborative realistic settings are advised to train various skills, and especially turn-taking (Dechsling et al., 2021). Since little information is advised, simplified cartoonish avatars with customization possibilities are preferred to represent the others as well as the self (Bozgeyikli et al., 2018; Newbutt, 2013; n=1). The avatar of the child has to be positioned at real-world height (Bozgeyikli et al., 2018). Moreover, due to common perceptual filtering difficulties, only hearing others' avatars instead of both hearing and seeing them can be preferred (Newbutt, 2013).

Discussion

Summary of Results

The first objective of this article was to check whether autism stakeholders' XR needs matched the existing XR uses. Our comparison between 34 interviews, mainly conducted with practitioners, and the literature, revealed that whereas more than 87 percent of the studies focus on training socio-emotional abilities, participants mentioned three main XR objectives, i.e., *well-being and mediation*, *social and cognitive training*, and *sensoriality* (see table 5). These objectives simultaneously draw upon the main features of practitioners' interventions without or with digital tools (see tables 3 and 4). This gap calls for more research to explore XR sensory-based and mediation approaches, and more considering autistic individuals requiring high support. These objectives are also strongly inclusive and bridge the gap between a mere focus on training abilities and an only focus on changing the society to improve the well-being of autistic individuals. To that respect, our findings extend Parsons et al. (2019)'s research roadmap for the XR medium. Possible use cases that implement these categories, and particularly benefit from using AR, are discussed in the next subsection. The second objective of this article was to provide XR design guidelines that are representative of autism stakeholders. Whereas the guidelines from the interviews and XR autism literature presented similarities, gaps also emerged (see table 6). More specifically, stakeholders advocated for paying more attention to the intervention context and for using more collaborative designs. XR design guidelines are outlined in the third subsection, followed by limitations to this work.

Suggestions of Use Cases for Future Autism XR Research

To train social abilities, using VR social scenarii (e.g., school playground) with a precise control of all stimuli by the practitioner are suggested. Yet, due to the autism literal way of learning, more research is needed to maximize the generalization of skills learned from VR into real-life (Bozgeyikli et al., 2018). Moreover, whereas quickly shifting between different use cases could enhance the intended outcomes (Dechsling et al., 2021), two participants stress that the richness of real-life situations could not be recreated. Hence, VR training should be considered as part of the overall intervention program, and within a gradual transition from VR to AR and finally real life. For instance, a bakery scenario consisting in buying bread could first be trained in VR, to limit possible anxiety, and then in a real bakery, using AR to withdraw distressing information (e.g., lights) and add contextual elements (e.g., emotion detection). This VR-AR progression could help to gradually work in more ecological contexts due to AR capabilities (Berenguer et al., 2020), and to maximize the generalization of the skills learned by gradually confronting the child to the unpredictability of real-life. These finding extend the complementary training and prosthetic roles previously assigned to VR and AR by Tarantino et al. (2019).

To make the child in an optimal secure state, three XR sensory-based approaches which draw upon common interventions emerged, i.e., multisensory relaxing spaces, derivatives of stereotypies, and mediation spaces.

Creating collaborative multisensory relaxing XR spaces largely emerged, often Snoezelen-inspired. A psychometrician described them as "sensory backpacks". To that respect, whereas VR can offer a precise control over all stimuli, it also displays risks of isolation (Parsons and Mitchell, 2002). Moreover, due to common autistic proprioception and symbolization difficulties, children could misunderstand the avatar representations of themselves and the practitioner. Thus, this could prevent the use of such scenarii for children needing high support. Even if AR also presents risks of isolation (Berenguer et al., 2020), AR sensory approaches could overcome these issues by perceiving the real surroundings and not using avatars. Thus, their low appearance in surveys (Berenguer et al., 2020; Mesa-Gresa et al., 2018) calls for more research. Possible use cases include real spaces where the proportion of real and virtual elements could be adapted to the session's needs, e.g., withdrawing posters on walls. Some participants advise creating XR derivatives of stereotypies to replace with a non-stigmatizing XR approach the repetitive behaviors that children often use to calm themselves but are often considered as non-socially appropriate. Regarding that unexplored approach, both VR and AR call for more research. VR use cases could be considered if a whole context must be recreated. For instance, one team supervisor mentioned the case of a boy who needs to be driven by his parents on Paris ring-road to get relaxed. Recreating this context in VR could support both the boy and his family. AR could be also used for recreating specific elements, e.g., spinning objects.

At last, XR mediation activities focus on strengthening the therapeutic alliance through collaborative free play activities, to prompt symbolization processes, as common mediation activities (Brun, 2013). Yet, whereas the *activity theory* (Engeström et al., 1999) considers technology as mediating tools that encourage social processes, they remain unexplored in XR. Yet, according to a psychologist, this approach raises some psychology research questions, for instance to explore the concept of potential space (Winnicott, 1999), i.e., an intermediary area between the subjective experience and the objective reality for playful and creative experiences. Such approaches could draw upon previous non-XR digitally-augmented multisensory experiences which displayed promising outcomes about the therapeutic alliance (Brown et al., 2016; Garzotto and Gelsomini, 2018; Gelsomini et al., 2019; Mora-Guiard et al., 2017; Pares et al., 2005; Ringland et al., 2014). They allowed to trigger multiple stimuli through body movements and various interfaces (e.g., reactive surfaces). *Mediate* was conducted in a large space (Pares et al., 2005), *Magic Room* (Garzotto and Gelsomini, 2018), *Magika* (Gelsomini et al., 2019), *Sensory Paint* (Ringland et al., 2014), and *Land of Fog* (Mora-Guiard et al., 2017) took place in smaller spaces, and *Responsive Dome Environment* relied on a dome-like space (Brown et al., 2016). Yet, these bespoke projects can be expensive and/or lack of flexibility. XR research should consider overcoming these limits with HMD-based AR.

XR sensory-based playful activities allow to assess or rehabilitate sensory disorders, or work on action/reaction principles, often by gradually adding/removing stimuli. VR and AR both provide solutions for creating such scenarii. The first half of the participants mention VR Snoezelen-like scenarii. The other half mentions realistic scenarii ranging from VR to AR, for instance by starting in a controllable VR space, and gradually going to AR. A possible use case could consist in recreating a VR supermarket, and then work in the real supermarket while using AR to remove distressing elements and add contextual help. Such AR setups could also be used as daily compensation strategies, in line with common strategies (e.g., protection headphones). Hence, AR appears as highly inclusive, since it allows children to enter spaces usually considered as overwhelming. While such sensory-based AR scenarii remain under-explored, the current evolution of HMDs calls for more research in this area.

Suggestions of XR Autism Design Guidelines

XR task design draws upon many common intervention principles (see table 3), e.g., individualization, structuration, gradual challenges, or offering a sense of agency. Yet, contrary to the literature, stakeholders emphasize the importance of creating collaborative designs, as the success of common interventions largely relies on the therapeutic alliance. To that respect, AR seems promising, as it allows to connect with the familiar environment of the child, by perceiving the usual practitioners and not using avatars. Then, two practitioners remarked that many design requirements that are listed in table 6 draw from common educational practices, and in particular the ones of Piaget et al. (1969) and Montessori and George (1964). As these practices often advise to use handling activities, and as AR can easily be combined with tangibles, AR seems well-suited to extend them.

Methodological insights expand previous XR recommendations (Bozgeyikli et al., 2018), by suggesting to focus on two aspects of the intervention: the context, and the evaluation of the outcomes. About the context, creating a secure space to then be able to conduct experiments was less emphasized in the literature to our knowledge. On the short term it consists in offering predictability, i.e., before, during and after the session. To that respect, AR seems well-suited, due to the reasons above-mentioned. On the long term, XR protocols may split into two periods, i.e., first set the child in a secure state, and then train specific abilities. To assess the XR intervention outcomes, mixed methods (i.e. qualitative and quantitative methods) can be used to adapt to the diversity of autistic profiles. Although it remains challenging due to the overall intervention that children take part in, regular evaluations may help to infer their evolution over time. So far, no standardized XR questionnaire exists to assess the autistic user's experience, and XR studies mainly focus on observable features. Yet, some custom questionnaires have been created. For instance, Tarantino et al. (2019) suggest to focus on four main features, i.e., the impact of photorealism, the understanding of real vs. virtual elements, the body movements, and the active exploration. Creating such questionnaires leads to reconsider some commonly measured aspects with non-autistic individuals which affect autistic users differently. For instance, assessing the feeling of presence, i.e., the feeling of "being here" (Biocca, 1997), can already lead to ambiguous results with non-autistic children, and is even more questionable with some autistic children who may struggle to say if they feel present in real-life (Dautenhahn, 2000). Moreover, whereas photorealism may engage non-autistic users, it may distract autistic users (Tarantino et al., 2019). At last, self-report questionnaires that are used in most studies (Newbutt et al., 2020) cannot be used for individuals with intellectual impairments. This calls for more research to create such questionnaires, to be filled by practitioners, as well as the child if possible, in line with Aruanno et al. (2018)'s study. They could also be combined with physiological data to get anxiety markers, e.g., heart rate (Kuriakose and Lahiri, 2017). Yet, more research is also needed to understand which relevant factors allow to get insights about complex perceptions (e.g., engagement), while using low intrusive technologies, such as light bracelets (Simões et al., 2018).

About the design process, using participative design is advised, as suggested by prior research (Parsons et al., 2019), as well as conducting studies in clinical settings. Equipment choices must be made accordingly, depending both on the use context and on the intended task. While most stakeholders are positive about using HMDs, in line with the literature, they suggest that they must be used in a controlled way, i.e., with a practitioner. This paper also reveals that participants would prefer using task-dependent age recommendations, e.g., eight years old for mediation applications focusing on well-being purposes. This was absent from the literature to our knowledge.

About information presentation, in addition to simplifying the audiovisual content, in line with the 2D games that often appeal to autistic individuals (see table 4), and with Bozgeyikli et al. (2018)' findings, this paper suggests to adapt the graphics' realism both to the intended task and to the practitioners' preferences. Indeed, depending on the type of intervention that practitioners use (e.g., NDBI, or psychodynamic), they may prefer using non-realistic creative scenarii, or realistic scenarii. Giving control over the audiovisual speed and prosody is also advised, as in Tardif et al. (2017)'s study. Indeed, decreasing the audiovisual speed may increase the child's understanding. At last, adding some unexpected events within a highly-structured XR space to enhance engagement connects with Remington et al. (2019)'s findings, which stress that using too little or too many distractors may hinder the attention of autistic children. This recommendation is also linked with common compensation strategies that individuals with Attention-Deficit Hyperactivity Disorder use to focus. Hence, future XR autism research may consider neurodevelopmental disorders in general, due to its potential impacts beyond the scope of autism.

Limitations

Findings must be considered in the light of some limitations. Interviews were mainly conducted with practitioners, since XR guidelines aimed at supporting their interventions. Yet, this may have led to less consider the views of autistic individuals. Moreover, no single stakeholder could expertly provide insights about XR, but only suggestions based on their knowledge of common interventions with or without digital tools.

The evaluation of the included publications in terms of design features was conducted qualitatively and may contain inaccuracies. Also, no systematic literature review of XR design guidelines was made, and the articles were mainly hand-searched. Conducting such a systematic review about XR design guidelines and comparing it with our interviews' findings may yield further design insights.

The evolution of the understanding of the autism field by the first author throughout the interview process may have gradually changed his way to ask questions to the interviewees, and to adapt to them. This also may have led to elicit more answers over time. Elements from the first author' background also may have influenced the results of the grounded theory analysis. At last, as the first author is not a native English speaker, translating interviews from French to English may have led to inaccuracies, even if efforts were made to remain close to the original wordings during the process.

Only interviewing French speaking participants may have led to overlook some insights, possibly being more prominent with international stakeholders. This calls for future research to complement the present study by interviewing stakeholders from different countries and comparing their standpoints with our findings.

To complement and extend the findings from this paper, it will be particularly useful to conduct XR participative design workshops with autism stakeholders being representative from all autism fields.

Conclusion

XR autism research displays a strong potential for complementing existing common autism interventions due to embodied immersive multisensory capabilities. Though, most autism XR studies focus on training socio-emotional abilities and concern children requiring low support. To get insights over common interventions, and then derive XR use cases and designs that could better support practitioners and could concern the entire spectrum, 34 interviews were conducted with stakeholders, mainly including practitioners. They were then analyzed using a grounded theory approach, involving three steps. First, a classification of the data according to concepts and categories was built from the interviews. Second, emerging XR use cases from the interviews were compared with two systematic literature reviews (Berenguer et al., 2020; Mesa-Gresa et al., 2018) to look for potential gaps between practioners' needs and the objectives of existing studies. Finally, XR design guidelines were obtained by comparing the findings from the interviews with an autism XR literature survey that was built in relation to our emerging grounded theory. Findings reveal that most stakeholders already use technology-based approaches to support interventions, often with tablets and desktop computers. Drawing upon them, as well as common non-digital interventions, they were interested in three main categories of XR use cases: (a) mediation and well-being, (b) social and cognitive training, and (c) sensoriality. In addition to these categories, technical and practical guidelines emerged. The main technical guidelines suggest that future research should consider using AR rather than VR to target children from the entire spectrum. Indeed, AR appears to be more inclusive and ecological than VR, as it allows to perceive the real child's surroundings. Moreover, gradually going from VR to AR seems promising to prompt the generalization of the skills learned into real life. To do so, the practitioner could handle the real-virtual proportion depending on the child's abilities. The main practical guidelines suggest that XR designs should include collaboration capabilities. Furthermore, XR studies should be considered as part of the child's overall intervention program, for instance by conducting studies within the usual clinical setting of the child.

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Figure Caption Sheet

Figure 1. Method used to conduct and analyze the semi-directed interviews

Tables

Table 1. *Profiles of the participants*

	Practioners	Autistic individuals and relatives	Academics
Group size	n=29	n=4	n=1
Sub-group features	- Psychologists (n=6) - Speech therapists (n=6) - Team supervisors (n=5) - Psychometricians (n=5) - Music therapists (n=2) - Psychiatrists (n=2) - Occupational therapists (n=2) - Specialized educator (n=1)	- Autistic individuals requiring low support (n=2): alone or with family - Mothers of autistic children requiring high support (n=2)	- Researcher in psychopathology and neurodevelopmental disorders (n=1)
Gender (m/f)	10/18	3/1	0/1
Years of experience or age	- 20 years and above (n=16) - 10-20 years (n=5) - 5-10 years (n=8) - 0-5 years (n=1)	- 18-30 (n=1 - autistic individual) - 30-50 (n=1 - autistic individual; n=2 – mothers of autistic children)	- 20 years and above (n=1)
Intervention	- NDBI (n=9) - Integrative (n=8) - Sensory-based (n=7) - Psychodynamic (n=4) - Did not say (n=2)	- Preference for NDBI (n=4)	---
Sector of activity	- Private and public (n=14) - Public (n=10) - Private (n=5)	---	---
Experience with digital tools	- Computer/Tablet/Console (n=23) - Humanoid robot (n=2) - VR (n=2) (not for interventions)	- Computer/Tablet (n=4) - VR (n=1) (not for interventions)	None

Table 2. *Semi-directed questionnaire addressed to the participants*

	Basis of question	Additional keywords/phrasings to ask for more details
Phase 1: Demographics	Q1 – Common approaches used in interventions	NDBI/psychodynamic/sensory-based, etc.; collaboration with others.
	Q2 – Practitioner's background with respect to autism interventions	Years of experience; private or public sector.
Phase 2: Interview body	Q3 – Typical autism intervention *(removed for non-practitioners)*	Examples of easy and/or difficult session.
	Q4 – Evaluation methods used before/during intervention	Sensory profile; impact of sessions; generalization of skills; role of relatives.
	Q5 – Individualization of intervention over time	Number and planning of the sessions; impact of atypical perception.
	Q6 – Common intervention practices *(added after the 6th interview)*	Typical exercises; difficulties experienced; rewards; individualization; relationship with the practitioner; structuration of time and space; routines.
	Q7 – Use and role of playful activities during sessions	Motivation; engagement.
	Q8 – Multisensory rehabilitation practices	Tools; environments; type of stimuli (visual, audio, tactile); method used.
	Q9 – Mediation practices in interventions	Music; dance; fine art; relationship with the practitioner.
	Q10 – Digital tools already used by the practitioner, and possible needs or viewpoints to that respect *(more explored with academics)*	Medium (i.e., tablets, robots, VAR); examples of games; collaboration with the practitioner; acceptability by children and practitioners; ideal digital tool.
	Q11 – Virtual or augmented reality environments that the practitioner would be interested in *(more explored with academics)*	Adaptability; evaluation; sensory processing disorders; social aspects; covering the entire autism spectrum.
	QA1 - Views about common interventions *(for autistic participants)*	
	QA2 –Atypical autistic perception *(for autistic participants)*	
Phase 3: Ending	Q12 – Any element that the practitioner would like to add	--
	Q13 – Other relevant experts to contact	

Table 3. *Autism interventions without the use of digital tools mentioned by the participants*

Category	Concept	Sub-concept	Examples / Details
Individualize interventions (n=33)	Start from the child's interests (n=32)	Create game depending on the purpose (n=10)	Game must depend on child's interests (n=4), skills (n=2), fears (n=1)
		Individualize rewards (n=16)	
	Individualize communication method (n=17)	Use alternative communication system (n=16)	Use pictograms / gestures, e.g., PECS (n=14) & Makaton (n=7) systems
		Communicate through mediation activites (n=4)	Use any game (n=3) or object (n=1)
	Individualize sessions (n=14)		Session has to depend on the child's state, e.g., fatigue (n=6)
	Build personalized project (n=13)		Set personalized long-term goals based on evaluations (n=13)
	Individualize care method (n=6)		No method suitable for every child exists (n=6)
Engage children in their intervention program (n=33)	Build and strengthen the therapeutic alliance (n=30)	Use individualized playful activites (n=27)	Use mediation activities (n=24), e.g., music (n=14), fine arts (n=5)
			Use any appealing games (n=12), e.g., video games (n=5)
			Use autistic interests: sensory stimulation (n=6), music (n=5), machines (n=4), geometric shapes (n=3), things that spin (n=3), bubbles (n=3)
		Adapt the practitioner's behaviors depending on the child (n=19)	Be slow and enveloping (n=12), e.g., adjust voice intensity (n=4), Do not over anticipate (n=3), Adopt the child's pace (n=2)
			Provide meaningful explanations (n=8)
			Understand the "autistic world" (n=8), e.g., Allow stereotypies (n=1)
		Create a secure relationship with the child (n=14)	Create a secure relationship (n=9); Enjoy the activity conducted (n=7)
	Use playful activites (n=26)	Adapt game based on the intervention goal (n=25)	Goal can be social (n=13), cognitive (n=5), sensory (n=4)
		Entertain the child and widen his interests (n=4)	
		Increase the child's autonomy (n=2)	
	Use behavioral strategies (n=26)	Use rewards (n=19)	Use sensory-based rewards (n=9), the token economy method[1] (n=5), or verbal congrats (n=4)
		Gradually increase the challenge (n=18)	Gradually adjust sensory loads (n=13), helping strategies (n=3), number of elements (n=3), therapist place (n=1)
		The child imitates the practitioner (n=7)	
		Use physical prompts (n=4)	
		Set things available to prompt demands (n=3)	
	Provide a sense of agency (n=16)		Give choice over a few tasks (n=16), offer possibilities to move (n=1)
	Alternate activities (n=15)	Alternate types of activity (n=15)	Use challenging vs. appealing (n=13), known vs. unknown tasks (n=1)
			Often change activities (n=3)
		Alternate ways to work on activities (n=3)	Task can be done sitting (n=3), moving (n=3), outside (n=1)
	Use compensation strategies to relax the child (n=14)	Make the child available for performing challenging tasks (n=12)	Use sensory stimulation (n=7), relaxing activity (n=4), start from stereotypic behaviors (n=2)
		Give daily strategies to prevent meltdowns (n=4)	Use derivatives of stereotypies (n=2)
Assess the state of the individual over time (n=29)	Assess child state on the long-term (n=28)	Conduct sensory evaluation (n=21)	Conduct sensory profiles (n=20), clinical observations (n=9), sensorimotor evaluation (n=4)
		Conduct psycho-developmental evaluation (n=18)	Assess developmental state and autism severity (n=15), language skills (n=8), conduct clinical observations (n=5)
		Ask questions to parents (n=10)	Use discussions (n=7) and questionnaires (n=3)
	Assess the child evolution on the short term (n=21)	Carry out observation of sessions(n=18)	Take notes (n=3), observe number of shared attentions (n=3) and stereotypic behaviors (n=2), new interests (n=3)
		Assess child at different intervention times (n=8)	Carry out specific assessments (n=8)
		Discuss with people knowing the child (n=8)	Discuss with relatives (n=8), people at school (n=2)
Structure the intervention program (n=27)	Offer predictability of intervention program (n=27)	Offer time predicability (n=21)	Show visual planning at session start (n=6) and timers (n=4)
			Finish session with appealing activity (n=4)
		Offer space predictability (n=19)	Use clear learning areas (n=6), clean space before child arrives (n=3)
			Show pictures of activities before to start (n=2)
		Use routines (n=17)	Ritualize activities and their organization (n=14)
			Repeat activites (n=6)
		Use same methods in all activities/spaces (n=9)	Provide parental advice (n=9)
	Structure intervention over different periods (n=11)	Observe individual to detect his interests (n=8)	
		Build the relationship with the child (n=7)	
	Don't overuse structuration (n=6)	Prepare for real life unpredictability (n=4)	
		Over structuration can prompt ritualization (n=3)	
Face difficulties in interventions (n=27)	Face difficulties working with autistic individuals and their families (n=21)	Find the suitable individualized intervention approach (n=15)	Some sensory channels remain hard to stimulate (n=7)
			Assess the impact of the intervention (n=6)
			Help without stigmatizing (n=4)
			Make activities meaningful (n=2)
		Build the therapeutic alliance (n=9)	Understand the child's actions and feelings (n=6)
			Handle heteroaggressivity (n=3)
		Reassure parents regarding possible fears (n=8)	Fears of the methods used (n=6) and institution(n=4)
	Face difficulties due to the healthcare system (n=20)	Face activity-related difficulties (n=14)	Health environment differs from daily life (n=9)
			Face difficulties linked with private/public work context (n=7)
			Healthcare equipment is often expensive (n=3), e.g., Snoezelen
		Face difficulties external to one's practice (n=12)	Sensoriality in interventions remains new (n=6)
			Face lack of specialized practitioners (n=6)
Work on sensoriality in intervention (n=26)	Work on sensory processing disorders (n=21)	Conduct gradual sensory habituation (n=15)	Gradually adjust specific sensory loads (n=13)
			Work in flexible multisensory environment (n=8)
		Modulate audiovisual information speed (n=7)	Use Logiral (n=6) (Tardif et al. 2017) or Youtube (n=1)
		Work on multisensory representations (n=5)	Use sensory lottos[3] (n=5); Gradually adjust sensory density (n=1)
		Use contrasted sensory elements (n=3)	Use environmental contrast in multisensory spaces (n=2)
	Provide multisensory environmental adaptations (n=20)	Offer sensory loads to regulate the child sensorimotor balance (n=13)	Give specific simulation based on child particularities (n=9)
			Work in adjustable multisensory environment (n=8)
		Use sensory protections (n=12)	Protections can be audio (n=12) (headphones), tactile (n=2), (smooth ground cover), visual (n=1) (sunglasses)
		Work in a neutral environment (n=11)	Limit environmental sensory information: visual distractors (n=6) (posters on walls…), Neutral colour of walls (n=3)

[1]Token economy method can be situated within ABA methods. It uses systematic reinforcements of target behaviors, with "tokens" that can be exchanged for other rewards.

Table 4. *Autism interventions already using digital tools mentioned by the participants*

Category	Sub-category	Content description	Game name (when mentioned) & Medium	
			2D graphics	**3D graphics / other**
Social skills (38% / n=13)	Social skills and emotions (n=4)	Video modeling (n=2)		Youtube or other applications (C/P, 3D, n=2)
		Social scenario (n=3)	*Autimo* (P, n=1)(Auticiel, 2015)	*JeMiME* (C,3D,n=1)(Grossard et al., 2019) *JeStiMuLE* (C,3D,n=1)(Serret et al., 2014)
	Group activities (n=2)	Video game workshop (n=2)	*Degrees of Separation* (C/PS, n=1)(Moondrop, 2019)	*Human Full Flat* (C/PS,3D,n=1)(No Brakes Games, 2016) *Ico* (C/PS,3D,n=1)(Sony Interactive Entertainment, 2011)
		Storytelling workshop (n=1)	NS	Research project (R, Other, n=1) (Duris and Clément, 2018)
Assistive technologies (38% / n=13)	Alternate and Augmented Communication (n=12)	Tailored pictograms (n=12)	*NikiTalk* (P, n=3)(La Rocca, 2019) *Snap Core* (C/P, n=2)(Tobii Dynavox, 2021) *LetMeTalk* (P, n=1)(appNotize UG, 2014) *Dis-moi!* (P, n=1)(Caulavier, 2013) *Proloquo2Go*(P,n=1)(AssistiveWare, 2013) *Avaz* (P, n=1)(Avaz, Inc., 2020) *CommunicoTool* (P, n=1)(C..Texdev, 2016)	NS
	Daily planning (n=1)	Visual planning (n=1)	--	NS
Mediation / Well-being (29% / n=10)	Rewarding activity(n=10)	*Any appealing game*	Application allowing to burst balloons (P, n=1)	Youtube Channels (C/P, NS, n=1)
	Mediation (n=4)	*Any appealing game*	*Angry birds* (all,n=2)(Rovio,2009) *Bumpy* (Cons, n=1)(Loriciels, 1989) *Théâtre de Minuit* (C,n=1)(Dada Média, 1999) Various brick breaker games (T/C, n=1) Video game displaying an aquarium (C, n=1) *Tetris* (all, n=1)(Pajitnov, 1984) *My Talking Panda* (P, n=1)(Sofia_Soft, 2017) *MyPiano* (P, n=1)(Trajkovski Labs, 2000) *Real Drum* (P, n=1)(Kolb Sistemas, 2012) *Noogra Nuts* (C/P, n=1)(Bengigi, 2012) Games based on « Simon Says » (all, n=1) *Talking Ginger* (P, n=3)(Outfit7, 2012)	*GTA Vice City* (Cons, 3D, n=1)(Rockstar North, 2015)
Education (24% / n=8)	Cognitive remediation (n=8)	Programming workshop (n=2)	NS	*RobAutisme* (C/R, other, n=1)(Sakka et al., 2018) *Scratch* Programming Language (C, other, n=1)(Resnick, 2006)
		Appealing game, e.g., puzzle, memory game (n=7)	*Cognibulles* (C,2D,n=1)(Virole and Wierzbicki, 2011) *BitsBoard* (P, 2D,n=1)(2021)	*School* (P, n=1, other)(LearnEnjoy, 2012) *Watch'n'Learn* (P, n=1, other)(Peters, 2018)
	Narrative understanding (n=1)	Storytelling workshop (n=1)	Research project (R, n=1) (Duris and Clément, 2018)	NS
	Daily living skills (n=1)	Activity: brushing teeth (n=1)	*Ben le Koala* (P, n=1)(Happy Moose Apps, 2017)	NS
Sensoriality (24% / n=8)	Multisensory Binding (n=6)	Looking at videos and slowing down their speed (n=4)	NS	Youtube (Any, n=1, other) *Logiral* (C/P, n=3, other)(Tardif et al., 2017)
		Playful activity to increase auditory understanding (n=1)	NS	Application for doing listening lottos[1] (NS, n=1, other)
		Playful activity with audio-tactile tangibles (n=2)	NS	Tangible allowing to play music (TI, n=1, other) Theremin instrument (TI, n=1, other)
	Psychomotor disorders (n=2)	Playful activity to work on fine motor skills (n=1)	NS	--
		Playful activity to work on gross motor skills (n=1)	NS	*Just dance* (Ki, n=1, 3D)(Ubisoft, 2009) Bowling application (Ki, n=1, 3D)
	Body consciousness (n=1)	Storytelling workshop (n=1)	NS	*RobAutisme* (C/R, n=1, other) (Sakka et al., 2018)
Diagnosis (6% / n=2)	___	Sensory profile (n=1)	NS	*SensoEval* and *SensoMott* (P, n=1, other)(Gorgy, 2012)
		Assessment of language understanding (n=1)	NS	--

C: Desktop Computer; P: Tablet and/or Phone; R: Robot; TI: Tangible Interface; PS: Projected Screen; Cons: Video Game Console; Ki: Kinect; NS: Non-specified.

[1]*Listening lottos* are listening games where the child has to listen to the sounds that are presented and then to associate them with the corresponding images.

Table5. *Fields of interests of the participants regarding XR use cases for autism interventions*

Category			Concept			Objectives	Examples	
Name	Weight		Name	Weight		Name	Participants	Literature (from MG and B reviews)
	P	L		P	L			
Mediation & Well-being	47% / n=16	MG: 3% B: 0%	Make the child available for challenging tasks	n=13	MG: 0% B:0%	Use individualized multisensory space (n=8)	Snoezelen-inspired (n=10), tipi-like spaces (n=1)	--
						Use individualized real stereotypies (n=3)	Breaking glasses (n=1), Being on a trampoline (n=1), in a car (n=1)	--
						Use audio-only appealing environment (n=2)		--
			Support the therapeutic alliance through mediation activities	n=6	MG:0% B:0%	Do creative activities (n=3)	Painting (n=2), Making music (n=2)	--
						Do any appealing activity (n=1)	Any activity for the child	--
						Use Snoezelen-like space (n=1)		--
			Enhance Well-being though Physical Activity	n=0	MG:3% B:0%	Give motivation to do sport (n=0, MG:3%, B:0%)		*Astrojumper* VR exergame-SSS (Finkelstein et al., 2013),
Social & cognitive training	41% / n=14	MG:87% B:95%	Train socio-emotional & Interactional abilities	n=14	MG:69% B:70%	Train Social & Interaction abilities (n=13, MG :45%, B:55%)	Real-life social scenarii (n=12): School (n=4), Cafeteria (n=2), transports (n=2)	Virtual dolphin to interact with as dolphin trainer – VR – R (Cai et al., 2013); Collaborative activity involving perspective-taking – VR – C (Parsons, 2015); Extension of pictogram communication systems – AR – P (Taryadi and Kurniawan, 2018); Virtual agent using artificial intelligence– VR – M and Eye tracking (Bernardini et al., 2013)
						Anticipate fearful situations (n=7, MG: 3%, B:0%)	Medical examinations (n=6), Transports (n=2)	Real-life spaces (MG:3%): e.g., Individualized fearful scenes (e.g., dogs) – Blue Room VR Environment (RS)(Maskey et al., 2019)
						Train emotions (n=1, MG:21%, B:20%)	*NM*	Social scenarii (home scene, school bus, school library, tuck shop, physical education class on the playground) – Half-CAVE – VR (Ip et al., 2018); Facial expressions and emotions using an augmented storybook– AR – P (Chen et al., 2016)
			Train cognitive abilities	n=6	MG:18% B:25%	Train cognitive abilities (n=3, MG:5%, B:15%)	Adapting VB-MAPP (n=1) and Boehm concepts to XR (n=1)	Attention (n=0, MG:5%): Object Discrimination with small games, – AR – P (Escobedo et al., 2014); Grasp objects – VR – gesture and eye tracking (Manju et al., 2018)
						Train daily living skills (n=4, MG:13%, B:5%)	Indoor environment: Having a shower (n=2), Brushing their teeth (n=2)	Indoor environment: Brushing teeth - marker-based AR picture prompt to trigger a video model clip of a student (Cihak et al., 2016)
							Outdoor environment: *NM*	Outdoor environment: Real-life social scenarii (e.g., supermarket) - HMD-VR (Adjorlu et al., 2017);
						Train abstract thinking (n=1, MG:0%, B:5%)	Implicit humor in social situations (n=1)	Pretend-Play - PP & AR - C (Bai et al., 2015)
Sensoriality	38% / n=13	MG: 0% B:5%	Rehabilitate sensory disorders	n=10	MG:0% B:5%	Rehabilitate sensorimotor disorders (n=10, MG:0%, B:5%)	Sensory habituation to real-life scenarii (n=7): School (n=3), Supermarket (n=2), Daily situations (n=2)	
							Sensory integration in multisensory spaces (n=6): Snoezelen-like (n=6)	*SEMI* Project – Four interactive games - AR – Ki (Magrini et al., 2019)
			Assess sensory disorders	n=6	MG:0% B:0%	Assess sensory disorders (n=4)	Real-life scenarii (n=2), e.g Supermarket (n=1)	--
							Non-realistic scenarii (n=2), e.g., Snoezelen (n=2)	--
						Assess progress over time (n=2)		--
			Work on action-reaction principles	n=4	MG:0% B:0%	Get inspiration from real-life scenarii (n=3)		--
Assistive Technologies	15% / n=5	MG: 0% B: 0%	Provide context relevant-only information	n=4	MG:0% B:0%	Add assistive virtual information (n=3)	Adding information to daily social situations (n=1), e.g., about emotions (n=1)	--
						Filter non-relevant information (n=2)	Filtering distressing noises (n=1)	--
			Support sensory strategies	n=1	MG:0% B:0%	Offer a resourceful sensory space (n=1)	Creating an AR tipi-life space (n=1)	--

AR: Augmented Reality, P: Participants, L: Literature, Comparison with Literature reviews in VR from Mesa Gresa (MG) and AR from Berenguer (B), R (Room-centric display), HMD: Head-Mounted Display, P: Tablet and/or phone; C: Desktop Computer, SS: Stereoscopic Surround-Screen, SM: Smartglasses, PP: Physical Props, M: Multitouch Display, Ki: Kinect, NM: not mentioned.

Table6. *Comparison of XR guidelines coming from the literature with suggestions from the participants*

Cat.	Concept	Sub-concept	Literature	Participants
Task design	Individualization	Content	*Individualize content*: Vary the tasks, interactions, stimuli, graphics (Bozgeyikli et al., 2018; Carlier et al., 2020; Dautenhahn, 2000; Dechsling et al., 2021; Parsons et al., 2019; Parsons et al., 2017; Tarantino et al., 2019; Whyte et al., 2015), add familiar objects into XR (Tang et al., 2019), or onto the real-environment with AR (Tarantino et al., 2019), use physiological data to tailor the content, e.g., gaze (Krishnappa Babu et al., 2018), heart rate, skin temperature (Kuriakose and Lahiri, 2017)	*Individualize content* (n=15): Set a familiar environment with reassuring elements (n=14), adjust every sensory information (n=5), possibly switch on/off every parameter (n=2), set an open/closed space depending on the individual (n=1), individualize rewards (n=1), integrate individualized and alternative communication systems (n=1)
Task design	Individualization	Medium	*Individualize medium according to the child's preferences* (Dechsling et al., 2021): Use CAVE system if HMD is not tolerated, or desktop computer or tablet if more feasible	*Individualize medium according to the child's preferences (n=1)*: Use tablet/desktop computer if HMD is not accepted
Task design	Engagement	Fun	*Make it playful:* Use a scoring system (Bozgeyikli et al., 2018; Kerns et al., 2017), challenges and hidden elements (Tang et al., 2019; Tsikinas and Xinogalos, 2019), storytelling and short/long term goals (Tang et al., 2019; Whyte et al., 2015), non-linear gameplay (Tang et al., 2019), digital companion (Tang et al., 2019), immediate feedback, and customization of avatars	*Make it playful (n=5)*: Use individual's interests (n=5) (i.e., music (n=3), circular elements (n=2)), visualize progress (e.g., scoring system, collectables) (n=3), use feedbacks/feedforwards (n=2), use rewards (n=2), play around presence/absence (n=2), play with their own shadow (n=1)
Task design	Engagement	Discovery	*Prompt discovery*: Use various non-concurrent elements (Bozgeyikli et al., 2018), e.g., movement (Bozgeyikli et al., 2018; Dautenhahn, 2000), shapes (Bozgeyikli et al., 2018), audiovisual stimuli (Carlier et al., 2020), 3D animations (Bozgeyikli et al., 2018), as well as unexpected elements (Alcorn et al., 2014; Brown et al., 2016; Virole, 2014)	*Prompt discovery*: Use unexpected elements (n=3), use various non-concurrent elements (e.g., audiovisual stimuli surrounding the child) (n=1)
Task design	Engagement	Discovery	*Broaden the child's attention* (Dechsling et al., 2021): Use eye-tracking to detect fixations.	
Task design	Engagement	Body perception	*See oneself in XR* (Bozgeyikli et al., 2018)	*See oneself in XR (n=1)*: See one's shadow (n=1)
Task design	Engagement	Environmental arrangement	*Gradually increase/decrease*: motor and cognitive complexity (Bozgeyikli et al., 2018; Carlier et al., 2020; Dechsling et al., 2021; Tang et al., 2019; Tarantino et al., 2019; Whyte et al., 2015), i.e., number of elements (e.g., crowdedness, stimuli, dynamism)(Tarantino et al., 2019) or types of elements (e.g., shapes, avatar's reactions, instructions, gestural prompts) (Dechsling et al. 2021)	*Gradually increase/decrease (n=13)*: number and types of stimuli (n=8), realism level (for social scenarii) (n=4), predictability (n=3), environment neutrality (n=3), number of controllable elements (n=1), number of distractors (n=1), dynamism (n=1), prompts (n=1)
Task design	Engagement	Rewards	*Individualize rewards* (Dechsling et al., 2021; Tang et al., 2019): Use personal (Kientz et al., 2013; Whyte et al., 2015) sensory-based (Bozgeyikli et al., 2018; Carlier et al., 2020) or generic (Constantin et al., 2017) rewards, often assess new child's rewards (Dechsling et al., 2021)	*Individualize rewards (n=1)*
Task design	Engagement	Rewards	*Adjust rewards:* Consider the child's performance and progression (e.g., antecedents and behaviors) (Constantin et al., 2017; Dechsling et al., 2021), as well as the child's abilities (Dechsling et al., 2021)	
Task design	Engagement	Sense of agency	*Make the child feel in control* (Bozgeyikli et al., 2018; Dautenhahn, 2000; Parsons et al., 2019; Spiel et al., 2019): Use child-initiated episodes (e.g., from what they like, or by making them choose between different actions/activites/game pathways) (Dechsling et al., 2021; Pares et al., 2005; Parsons et al., 2019; Tang et al., 2019; Whyte et al., 2015), adjust the information speed (Tardif et al., 2017), make the environment respond to various actions (e.g., gestures, voice) (Pares et al., 2005)	*Make the child feel in control (n=14)*: Use child-initiated episodes (e.g., from what they like, or by making them choose between different activities (n=6)), give them the possibility to freely move in space (n=2)
Task design	Engagement	Sense of agency	*Allow the user to author the XR environment* (Parsons et al., 2019)	*Allow the user to author the XR environment (n=3)*: Record and repeat sounds or videos (n=3)
Task design	Engagement	Imitation	*Use modelling partners who simulate situations* (Dechsling et al., 2021), e.g., peers, avatars	*Use modelling partners who simulate situations* (n=1)
Task design	Engagement	Imitation	*Use avatars who imitate the child* (Dechsling et al., 2021), e.g., language, play, and body movements	*Use avatars who imitate the child* (n=1)
Task design	Sensoriality & perception	Structuration of time & space	*Offer predictability* (Bozgeyikli et al., 2018; Carlier et al., 2020; Dautenhahn, 2000): Avoid loud sudden sounds (Bozgeyikli et al., 2018)	*Offer predictability (n=8):* Use little distractors (n=6), use visual activity timers (n=3), alert about the presence of stimuli (n=2)
Task design	Sensoriality & perception	Structuration of time & space	*Give repetition possibilities* (Bozgeyikli et al., 2018; Carlier et al., 2020; Lorenzo et al., 2019): e.g., routine in training (Bozgeyikli et al., 2018; Carlier et al., 2020)	*Give repetition possibilities (n=10)*
Task design	Sensoriality & perception	Interaction types	*Use accessible interaction types* (Bozgeyikli et al., 2018; Brown et al., 2016; Parsons et al., 2019), e.g., speech recognition (Halabi et al., 2017), or touchless interaction (Bartoli et al., 2014)	*Use accessible interaction types (n=4)*: ergonomic controllers (n=4), tangibles XR controllers (n=3)
Task design	Sensoriality & perception	Interaction types	*Offer various ways to interact* (Bozgeyikli et al., 2018; Pares et al., 2005; Parsons et al., 2019)	
Task design	Sensoriality & perception	Interaction types	*Use motion-based embodied interaction* (Bartoli et al., 2014; Brown et al., 2016; Dautenhahn, 2000)	*Use motion-based embodied interaction (n=1)*: no teleportation (n=1)
Task design	Sensoriality & perception	Meaningful experiences	*Draw links with the real world* (Bozgeyikli et al., 2018; Tang et al., 2019)	*Draw links with the real world (n=1)*
Task design	Sensoriality & perception	Meaningful experiences	*Make experiences meaningful* (Dautenhahn, 2000): Consider autism perception, e.g., visual memory (Bozgeyikli et al., 2018), and associative way of thinking (Dechsling et al., 2021; Virole, 2014)	*Make experiences meaningful (n=1)*: Use individualized communication system of the child in XR (n=1)
Task design	Collaboration	Prompting & Reassurance	*A practitioner/relative can prompt the child* (Dechsling et al., 2021; Parsons et al., 2019), e.g., instructions, gestures, physical prompts	*The practitioner/relative can prompt the child (n=2)*, e.g., to help (n=2)
Task design	Collaboration	Prompting & Reassurance	*The child can see the practitioner*, e.g., for reassurance (Dautenhahn, 2000)	*The child can see the* practitioner (n=10): for reassurance (n=2) or if context-relevant (n=2)
Task design	Collaboration	Shared controls		*Share controls between the child and practitioner* (n=10)

Protocol to conduct XR sessions	Intervention context	Secure environment	*Give predictability:* Practitioners may wear the HMD and suggest the child to handle it before to wear it (Garzotto et al., 2017)	*Give predictability (n=5)*: Make the planning clear before to start (n=3), use pictograms showing what the XR space will look like (n=1), practitioners may wear the HMD before the child (n=1)
			Make the experience meaningful for the child: Combine different elements and strategies (Dechsling et al., 2021)	*Make the experience meaningful for the child:* Use understandable vocabulary to present the experience (n=4), make sure everything is understood prior to start (n=2)
				The practitioner can control every XR parameter (n=9): See what the child sees (n=2)
		Organization of sessions		*Get the child used to the system during first sessions (n=3)*: Possibly use sensory habituation to the HMD (n=3), use free play to detect the child's preferences (n=1)
			Keep the child engaged: Make short sessions with breaks (Bozgeyikli et al., 2018)	*Keep child engaged (n=8)*: Alternate work and relaxation activities in XR (n=5), alternate work in XR and in real life (n=2)**;** keep sessions short (n=1) (e.g., around 15mn)
			Include XR experiment as part of the global intervention: Make long-term studies (Bozgeyikli et al., 2018; Robins et al., 2004)	*Include XR experiment as part of the global intervention (n=4):* Have regular sessions every week (n=2); use XR at specific moments of the therapy (n=1), make long-term studies (n=1)
			Establish detailed procedures and provide training for the practitioners (Dechsling et al., 2021)	
	Mixed methods	Quantitative Evaluation	*Assess the child's state before the experience* (Malihi et al., 2020; Maskey et al., 2019)	*Assess initial state of the child (n=1):* Conduct sensory profile
			Assess the child' experience: No consensus exists: Collect behavioral data (Dechsling et al., 2021), e.g., repetitive behaviors (Pares et al., 2005), interaction logs (Dechsling et al., 2021), eye-tracking (Dechsling et al., 2021; Koirala et al., 2019); collect physiological data (Kuriakose and Lahiri, 2017); use custom questionnaires (Aruanno et al., 2018; Garzotto et al., 2017; Garzotto and Gelsomini, 2018; Tarantino et al., 2019); use common XR presence/anxiety questionnaires (Malihi et al., 2020; Wallace et al. 2010, 2017); use autism intervention questionnaires (Malihi et al., 2020; Maskey et al., 2019)	*Assess the child' experience and* performance (n=2): Collect physiological data for stress measurement (e.g., biosensors, pressure sensors) (n=2), log observational data (n=2)
			Assess practioners' actions (Dechsling et al., 2021), e.g., behavioral data, prospective adjustments	
			Measure the ongoing progress (Dechsling et al., 2021): Collect data from multiple measures	
		Qualitative Evaluation	*Conduct behavioral observations*: Film sessions (Pares et al., 2005) and take notes (Brown et al., 2016)	*Conduct behavioral observations (n=2)*: film sessions (n=2), take notes (n=1)
			Conduct interviews, i.e., with caregivers/parents (Pares et al., 2005) and children (use videos, images, drawings if non-verbal, and closed questions, with screenshots, smileys if verbal) (Spiel et al., 2017)	*Carry out interviews (n=1)*: if children can answer (n=1)
Design process	Participative design	Participative design	*Use participative design* (Bozgeyikli et al., 2018; Brosnan et al., 2019; Dechsling et al., 2021; Parsons et al., 2019; Spiel et al., 2019): Value the design experience of the child (Parsons et al., 2019)	*Use participative design (n=5)*
			Explicit all questions between stakeholders before to engage in collaboration (Parsons et al., 2019)	
		Inclusivity	*Consider the entire autism spectrum*: Consider autism strengths and difficulties, include individuals requiring substantial support and adults (Bozgeyikli et al., 2018; Parsons et al., 2019)	*Consider the entire autism spectrum (n=7)*: Include individuals requiring substantial support (n=5) and adults (n=2)
	Equipment	Context-Dependent	*Use ergonomic and affordable equipment*, i.e., light (Bozgeyikli et al., 2018), portable, small (Newbutt et al., 2016), non-tethered , affordable (Parsons et al., 2019)	*Use ergonomic and affordable equipment (n=4):* resistive (n=3), not cumbersome (n=2), portable (n=2), affordable by using HMDs (n=2), non-tethered or with long wires (n=1)
		Task-dependent	*Use AR to aid in the generalization from virtual to the real world* (Dechsling et al., 2021)	
	Use context	Setting	*Conduct experiments in ecological settings* (Bozgeyikli et al., 2018; Parsons et al., 2019)	*Conduct experiments in ecological settings (n=1)*
		Age range	*Age range***:** Possible from 13 years old for neurotypical people (Gent, 2016)	*Age range***:** is task-dependent (n=7)
Information presentation	Little & Clear Information	Little information	*Use little tasks to complete*, e.g., unique goal per gaming session (Carlier et al., 2020)	*Use little tasks to complete (n=4)*
			Avoid stimuli when not task-relevant (Bozgeyikli et al., 2018; Carlier et al., 2020; Virole, 2014): Use simplified graphics (Bozgeyikli et al., 2018; Tarantino et al., 2019)	*Avoid stimuli when not task-relevant*: Use neutral environment (n=7), use simplified graphics (n=4)
			Display clear information (Bozgeyikli et al., 2018): foreground/background differentiation, clutter-free	*Make information clearly visible (n=1)*: Use clear foreground/background differentiation
			Minimize transitions: between game states (no sound, animations) (Carlier et al., 2020)	*Minimize transitions (n=1):* Gradually decrease appealing stimuli before to remove the HMD
			Avoid using metaphors (Bozgeyikli et al., 2018)	*Avoid using metaphors (n=4)*
		Adaptation to the child's pace	*Make it possible to repeat or adjust information speed* (Tardif et al., 2017)	*Make it possible to repeat or adjust information speed (n=13)*
			Use minimal prosody: no emotions (Duris and Clément, 2018), little text/language (Carlier et al., 2020)	
	Task-dependent	Socio-emotional abilities	*Allow for rapid shifts between XR environments* (Dechsling et al., 2021)	*Use adjustable realistic naturalistic settings* (n=5): to enhance the generalization of skills
			Use adjustable realistic naturalistic settings (Dechsling et al., 2021): Support the adult-child relationship, give precise control over the virtual surroundings	
			Train a variety of skills instead of specific skills (Dechsling et al., 2021)	
			Train balanced turn-taking (Dechsling et al., 2021): Use various contexts, visual prompting, rewards	
		Others		*Realistic and non-realistic environments won't interest the same practitioners* (n=1)
	Avatars	Representation	*Use cartoonish non-human avatars* (Bozgeyikli et al., 2018; Newbutt, 2013)	*Use cartoonish non-human avatars* (n=1)
			Make XR avatars customizable (Bozgeyikli et al., 2018; Newbutt, 2013)	
			Only hear a XR avatar instead of both hearing and seeing it (Newbutt, 2013)	
			Position the avatars at real-world height (Bozgeyikli et al., 2018)	
		Use	*Use avatars as tutors for children* (Bozgeyikli et al., 2018)	