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Evaluating the Acceptability and Usability of a Head-Mounted Augmented Reality Approach for Autistic Children With High Support Needs

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Abstract. Virtual and Augmented Reality (VR and AR) are promising to complement practitioners' interventions with autistic children, but they mainly target the socio-emotional abilities of children with low support needs. For autistic children with high support needs, sensory-based and mediation approaches are advised with AR headsets, to keep contact with their familiar environment and their real practitioner, while VR presents risks of isolation. Yet, the acceptability and usability of AR headsets for these children remains unknown. Thus, this paper investigates the possibility to use AR headsets with Magic Bubbles, a multisensory environment designed for autistic children with high support needs, to reassure them while reinforcing the dyadic relationship with their practitioner. Drawing upon a previous design validation with 11 practitioners, acceptability and usability testings were conducted at a day hospital with 10 children with neurodevelopmental disorders and associated intellectual disability. Findings confirm a positive acceptability and usability for these children, thus validating the possibility to use Magic Bubbles with autistic children with high support needs. At last, future directions regarding the use of AR in clinical settings are outlined.

Keywords: Augmented Reality· User Experience · Multisensory · Autism Spectrum Disorder · Acceptability · Usability · Well-being · Children

1 Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition which concerns 1% of people worldwide [23]. It is mainly characterized by social communication and interaction difficulties, restricted interests, and repetitive behaviours [1, 23]. Autistic people[3] display these traits in various proportions. Some individuals have low support needs (LS) (e.g., to perform academic tasks), and others have high support needs (HS) (e.g., to perform daily tasks), being minimally

[3] This paper uses autism stakeholders' preferences in terms of terminology, e.g., identity first-language, with terms such as "autistic individual"[8]

verbal and with associated Intellectual Disability (ID) [23]. Recent research has largely overlooked children with HS [16], being absent from 94% of autism research published in 2016 [34]. This paper proposes to complement practitioners' interventions for children with HS through a technology-based approach.

Interventions for children with HS largely consist in reassuring the child and reinforcing the dyadic child-practitioner relationship, prior to work on other abilities (e.g., social abilities) [6, 35]. To that end, mediation sensory-based interventions are common, such as *Sensory Integration Therapy* [37, 3] or *Snoezelen* [21, 30]. Sensory Integration Therapy seeks to train multisensory interactive processes to gradually enhance developmental abilities, with various playful sensory objects (e.g., sensory balls). Snoezelen aims at reassuring and relaxing children to gradually reinforce the dyadic relationship, with multisensory spaces often including bubble columns. It is particularly promising for children with HS [30]. Yet, practitioners can struggle to conduct such interventions, especially with children with HS [20]. Difficulties can come from a lack of resources, of flexibility of the tools and environments, time constraints, or expensive cost [20].

Practitioners often use digital tools to complement their interventions, as being individualizable, controllable [6, 35], and often appealing [22]. They mainly target socio-developmental abilities through various mediums (e.g., tablet, computer, robot). Yet, such interventions lack of multisensory capabilities that are needed to work with autistic children with HS [6].

Some digitally-augmented multisensory spaces have been designed for autistic children, with successful outcomes over their well-being and the dyadic relationship [4, 14, 26, 31, 33]. Various settings were used: large spaces where physical items are augmented to trigger stimuli based on users' actions [4, 14, 31], a projected floor [26], or a projected screen and a Kinect camera [33]. Yet, equipment is often bespoke, bulky, or too expensive for clinical structures.

Virtual (VR) and Augmented (AR) Reality could overcome the limits of autism interventions with or without digital tools, by offering secure multisensory capabilities [12, 18, 25] through affordable Head-Mounted Displays (HMDs). Moreover, they allow to include all autistic children including those with HS [16]. Yet, children with HS are under-represented, as most studies focus on training socio-emotional abilities [25, 17, 27] which can be too advanced for them [6, 9].

A previous study revealed that autism stakeholders would prefer to use AR for children with HS, in order to augment their familiar surroundings while still seeing their real practitioner, whereas VR could isolate them [6]. In particular, AR use cases should focus on reassurance and reinforcing the dyadic child-practitioner relationship [6]. Such an AR environment called *Magic Bubbles* was designed and validated in collaboration with practitioners working on a daily basis with children with HS [5].

Unknowns remain about HMD's acceptability for autistic children with HS, as their positive acceptability was mainly suggested for children with LS [7, 10, 24, 36]. To our knowledge, only three studies suggested a positive acceptability for individuals with HS: for twelve adults in VR [29], for five children with neurodevelopmental disorders and ID in VR [15], and for twenty children with

neurodevelopmental disorders and ID in AR [2]. To complement them, this paper addresses three research questions:

1. Could autistic children with HS accept and use *Magic Bubbles* AR environment?
2. Could autistic children with HS get engaged with *Magic Bubbles* AR environment while still communicating with others?
3. Could autistic children with HS get secure when using *Magic Bubbles* AR environment?

To examine these three research questions, our team of researchers, coming both from the human-computer interaction field and the clinical field (two psychologists and one psychiatrist) conducted a study with 10 autistic children with HS, or similar traits, i.e., neurodevelopmental disorders and associated ID. Thus, this study extends a previous study that was only conducted with 11 practitioners as part of the design process of *Magic Bubbles* AR environment to ensure its acceptability among the clinical team [5]. After presenting the methodology that was used, the findings will be outlined, and then discussed.

2 Method

2.1 Participants

Two psychologists from our research team recruited 10 children with neurodevelopmental disorders and associated ID among the patients of the day hospital André Boulloche, in agreement with the clinical team. They include six boys and four girls, from 11 to 14 (MA:12.5, SD:0.98). Eight were minimally verbal and two were non-verbal. All children displayed significant intellectual disability, their Intellectual Quotient (IQ) ranging from 50 to 70. Four children had already experienced VR during cultural outings. None had experienced AR. The low number of children is imposed by the following inclusion criteria: children had to display a neurodevelopmental condition according to the ICD-10 [43], an associated ID, not display risks of epilepsy, and be at least 11 years old for using HMDs in line with recent AR/VR studies [2, 15, 24, 28]. As this low number is common in AR/VR studies for autism, mainly because this population is hard-to-reach [18, 25], it was deemed suitable to investigate our research questions. Moreover, according to the psychologists, the 3:2 male to female ratio among the recruited children would not influence the findings. Children's profiles are detailed in Table 1.

2.2 HMD-based AR environment tested with children

Magic Bubbles is a multisensory HMD-based AR environment which aims at complementing common practitioners' interventions for autistic children with HS, such as Snoezelen or Sensory Integration Therapy. The design process was first informed by 34 interviews with autism stakeholders [6], as suggested by

Table 1. Profiles of the children who participated to the study. M/F stands for Male/Female. IQ stands for Intellectual Quotient.

ID	M/F	Age	Condition (ICD-10)	IQ
1	M	13	Atypical autism (F841)	50< IQ<70
4	F	11	Other childhood disintegrative disorder (F843)	50< IQ<70
5	M	13	Other pervasive developmental disorders (F84.8)	50< IQ<70
6	M	13	Pervasive developmental disorder, unspecified (F849)	50< IQ<70
7	M	13	Pervasive developmental disorder, unspecified (F849)	50< IQ<70
8	M	14	Pervasive developmental disorder, unspecified (F849)	50< IQ<70
9	F	12	Mixed disorder of conduct and emotions, unspecified (F929)	50< IQ<70
14	F	12	Mixed specific developmental disorders (F83)	50< IQ<70
16	F	13	Atypical autism (F841)	50< IQ<70
17	M	11	Autistic disorder (F840)	50< IQ<70

Parsons et al. [32]'s research agenda. The design was then adapted for a day hospital context in collaboration with two psychologists, and validated through testings with 11 practitioners [5]. This subsection only summarizes the main features of *Magic Bubbles*, as a previous paper presents its full description [5].

Children can explore an augmented interaction space, while perceiving their practitioner, and interacting with audio, visuals, and controllers' vibrations. Stimuli are presented through common appealing objects (e.g., bubble columns) drawing upon common interventions. Stimuli are generic (e.g., bubbles) or individualized (e.g., music). Practitioners can prompt exploration and shared play by standing physically close to the child while perceiving what they see and hear through a screen monitor. The design is presented on Figure 1.

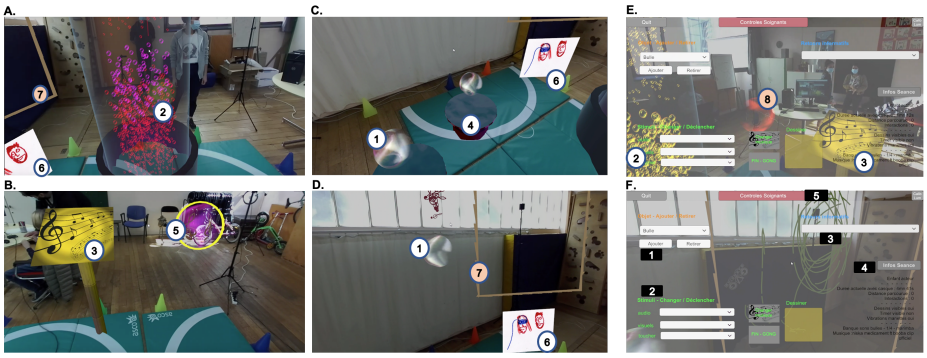

Fig. 1. Design of *Magic Bubbles* – Content: 1 Bubble; 2 Bubble column; 3 Panel; 4 Water pond; 5 Music bubble; 6 Image panel; 7 Drawing panel; 8 Recording bubble – Practitioner's UI (E,F): 1 Add/Remove objects; 2 Trigger stimuli; 3 Add/Remove feedback; 4 Show contextual information; 5 Show the UI (these images come from [5]).

Two conditions exist: spectator and actor. When spectator, the child can move in space without interacting with objects, but the practitioner can trigger all stimuli. When actor, the child can move and interact with everything.

Augmentation is presented through an AR see-through setup, by using a Zed-Mini camera plugged onto a HTC Vive Pro HMD, that "captures a live feed of the real environment, and then makes it visible inside the HMD, supplemented by virtual objects"[5]. Two HTC Vive controllers are used, as well as four Vive lighthouse outside-in tracking systems.

2.3 Development of the semi-structured questionnaire

To assess the experience of autistic children who cannot complete self-report questionnaires according to the psychologists, we had to build a new questionnaire that could be filled by their respective practitioners, as in Aruanno et al.[2]'s study. Hence, a two-part semi-directed questionnaire was devised to be filled by the practitioner in 5 to 10 minutes at the end of every child's AR session. Most questions use 1-5 likert scales, apart from questions addressing agency and engagement that use 1-7 likert scales, as drawing upon questionnaires with such scales [38, 42]. Practitioners can write additional details if necessary.

In the first part, six questions address the child's state, drawing upon stakeholders' interviews [6]. Question 1 (Q1) and Q2 ask if the child was anxious and tired prior to start, and Q3 and Q4 ask the same questions about the end. Q5 asks if the child got resourced and Q6 if they could start another activity at the end. As the questionnaire has to be filled in 10 minutes maximum so that practitioners can complete it, these questions intend to be quickly answered, and to only provide an overall picture of the child's state. Yet, they seek to collect key elements by relying on psychologists' expertise in autism and their knowledge of these children to integrate multiple aspects in order to provide a representative answer for each question.

In the second part, nineteen questions address the acceptability, usability, control, presence, engagement, and social interaction, inspired from questionnaires [11, 38, 42, 19], studies investigating the use of digital tools for autism [2, 14, 15], and interviews with stakeholders [6]. First, three questions focus on acceptability [2, 15], about: the easiness to wear the HMD (Q7), the annoyance due to wearing/removing it (Q8), and cybersickness' symptoms (e.g., nausea, oculomotor symptoms, disorientation)(Q9). Then six questions address usability [6, 11, 42], about: the platform's complexity (Q10), the amount of information (Q11), the need for support (Q12), the confidence (Q13) and easiness (Q14) when using the system, and the ability to interact and to move at the end (Q15). Then, agency is questioned [42] regarding the ability to identify stimuli (Q16), anticipate reactions (Q17), or actively control the environment (Q18). After that, presence is questioned [38, 2] about: the understanding of real versus virtual (Q19), the real-world awareness (Q20), the feeling of being captivated (Q21), and the consistency of the experience with respect to their usual real-world experience (Q22). Then engagement is addressed [2], about fun (Q23),

and involvement (Q24). After that, the level of communication is questioned [14] (Q25), and practitioners can add something if needed (Q26).

2.4 Procedure

All procedures were approved by *Poléthis* Ethics Research Committee of Paris-Saclay University under reference 226.

Before the experiment A psychiatrist explained the protocol to the child's legal tutors and collected their informed consent. Indeed, children were unable to do it by themselves according to the clinical team. As this study did not assess the differences induced by the actor and spectator conditions (see Subsection 2.2), practitioners affected children to each condition depending on their common interventions, and if they were mainly passive or active. Thus, ID4 and ID9 were affected to the spectator condition, and the others to the actor condition.

During the experiment The child tested the AR environment in a large room of the day hospital which is normally used for sensory-based activities. Four investigators were always present: two psychologists, one investigator being here for technical support, and one psychology intern. The child's educator could also come for reassurance or if interested, following common clinical practices. Sessions lasted between 5 minutes (minimum) and 20 minutes (maximum), depending on the child's acceptability, if they wanted to stop, or on practitioners' perception of their experience. Due to day hospital's constraints, unexpected events could impact the session (e.g., child being late as coming from the infirmary). Psychologists were used to the AR platform when starting the testings, as they participated to the AR design process beforehand [5]. Several sessions with different children were successively conducted, spaced by a 15-minute break to clean the equipment and air the room according to COVID security rules. Equipment was mounted (20 minutes) and dismounted (15 minutes) before and after all sessions.

At the session's beginning, psychologists introduced the child to the AR system and invited them to wear the HMD. Then, children experienced a free-play time, during which practitioners could interact with them (i.e., verbally or non-verbally) while monitoring what they perceived through the screen. Children were never forced to wear the HMD, and could remove/wear it at will. Session could end up in two ways: if children expressed that they wanted to stop (e.g., verbally, or by removing the HMD), or if time ran out. In this second case, practitioners warned that the session would end in one minute (verbally, and by triggering a gong sound in AR) and proposed to do one last action. After removing the HMD (by themselves or with practitioners' support), psychologists invited children to make a real drawing with a sheet of paper and pencils. Children only drew if they wanted to.

After the experiment After the child left, psychologists completed a semi-direction questionnaire (presented in Subsection 2.3). Then, we took notes to summarize the session's unfolding, by paying attention to critical incidents (e.g., unusual events). After the sessions of the six first children, to elicit more insights, semi-directed focus group interviews were added and conducted by the first author with the two psychologists and the intern to debrief about the sessions. They happened right after the sessions were conducted. The interviews with the practitioners relied on three main questions, asking if the child had fun, if they seemed to be reassured, and if they were ready to start other tasks when leaving.

2.5 Data collection

To assess children's experiences, multiple data sources were used to mitigate the bias due to each source. Data collected include: the semi-structured questionnaire, semi-directed interviews, first author's notes, and three video recordings (two cameras from different angles and the child's view). Moreover, efforts were made to get the child's perspective: by collecting their drawings, as suggested by Spiel et al. [40]'s study about autistic children's experiences with technology, and by filling the questionnaire while asking questions to the child, as in Aruanno et al. [2]'s study. Yet, only ID16 accepted to draw and only ID7 could answer questions. Thus, data collected mainly accounted for practitioners' perspective. In addition to that, we measured the time during which children wore the HMD. Collecting physiological data was also considered (e.g., heart rate) but abandoned, as the biosensors could hinder children's experience according to the psychologists. All data were anonymized by affecting identifiers to the children (see Table 1).

2.6 Data analysis

The first author transcribed the data collected. This process allowed to familiarize with it, to ask the psychologists for clarifications, or to check their ratings when not matching their comments. To do so, psychologists looked at the videos and made corrections when appropriate. Then, two main analytic stages were conducted in parallel, by different researchers, and with different methods, to mitigate potential biases. First, questionnaire's answers were analysed quantitatively by the first author, while considering practitioners' comments. Second, the interviews, notes, and videos were analyzed qualitatively. The first author analyzed the notes and interviews, and two other authors who are also clinical psychologists analyzed the videos. To do so, deductive content analysis was mainly used, complemented by inductive content analysis [13]. The two main analytic stages are detailed below.

Analyzing the semi-directed questionnaire Descriptive statistics were used to analyze the questionnaire's answers, as more advanced statistics were not

meaningful with respect to the low number of participants. Figures 2 and 3 respectively display the findings related to the user experience's categories (e.g., acceptability, usability), and to the evolution of the child's state between the beginning and the end of sessions. Findings are presented with respect to practitioners' comments, through different paragraphs accounting for the different categories (see Subsection 3.1). Moreover, an additional paragraph accounts for critical incidents that appeared from practitioners' comments. Questions about the feeling of presence were not analyzed, as not related to the current research objectives. They will be evaluated in a future paper.

Analyzing the notes, interviews and videos Deductive content analysis was mainly used to analyze the data with respect to the questionnaires' categories. The goal was to confirm and draw comparisons with the questionnaires' findings, as well as to gather further insights about the categories being assessed. To complement this approach, inductive content analysis was used, by constructing new categories from the data.

The first author analyzed the interviews and notes by doing open coding, with the data analysis software called *MaxQDA*[4]. To mitigate potential biases, constant comparison techniques were used to compare the initial data with the phrasings and categories that were gradually constructed. The psychologists analyzed the videos, based on their clinical expertise, as in previous studies [15]. The qualitative analysis process stopped when reaching data saturation. Findings were finally compared, and presented together in subsection 3.2.

3 Findings

Findings are presented in two subsections, accounting for the two main analytic stages that were used. First, questionnaires' answers are presented. Then, findings from the video observations, notes and interviews are presented. The times during which children wore the HMD are not presented as they happened to be unusable. Indeed, practitioners often wore the headset during sessions to support children's acceptability, and children often worn and removed the HMD multiple times, making it impossible to collect precise data.

3.1 Findings from the semi-directed questionnaire

Answers about the child's experience are first presented (Q7-Q16, Q23-25) (see Figure 2), and followed by answers about the child's state (Q1-Q6) (see Figure 3). Q17 and Q18 were removed as unanswered for most children. Indeed, practitioners deemed them too advanced for this discovery session, and thus impossible to answer. At last, critical incidents are presented.

[4] MaxQDA software: https://www.maxqda.com/

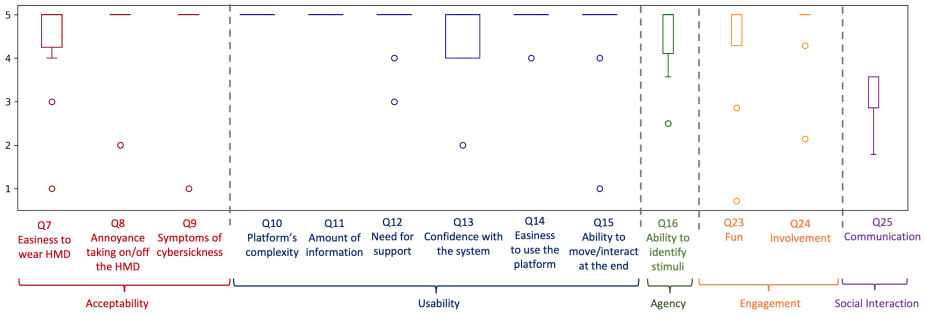

Fig. 2. Questionnaire's answers regarding the acceptability, usability, agency, engagement, and social interaction, for the 10 children with neurodevelopmental disorders and intellectual disability who tested *Magic Bubbles*. Q16, Q23, Q24 were displayed on 1-5 scales rather than 1-7 scales for enhanced readability. Bars represent the median, rectangles represent the interquartile range (IQR) (50% of the sample's values), and circles represent outliers.

Acceptability Most children easily accepted the HMD (Q7): seven very easily (5/5) and ID9 easily (4/5). Among them, ID8 wore it nearly alone, ID4 played to wear/remove it, and ID16 expressed a slight discomfort that was not precisely identified. Yet, ID6 had some difficulties (3/5), requiring support and preferring the HMD to be a bit unscrewed. ID17 wore it for a very short time (1/5), which is normal as he usually needs time to get used to new elements. Seven children had no discomfort (Q8-5/5), contrary to ID6 and ID8 (4/5). Indeed, ID16 removed the HMD after six minutes, and ID8 was frustrated to spend so much time to adjust it. Seven children did not experience cybersickness (Q9-5/5), but ID5 said that the image was "blurry" at the start. While no answer was given for ID6, he did not have a negative experience but looked surprised after removing the HMD. ID9 had cybersickness (1/5) and said that the image was blurry. Blurry images could be perceived due to the HMD not being screwed enough, and point at the difficulty to correctly adjust the HMD with such children.

Usability *Magic Bubbles*' complexity (Q10) was adapted to all children (5/5), and not mentioned for ID17 as he only wore it for a very short time. The psychologists advised using more complexity for three children, to not induce boredom over time (ID1), and for the spectator condition: "if actor, ID4 would have stayed longer". The amount of information (Q11) suited all children (5/5), but adding features was suggested for two of them. Most children required little practitioners' support (Q12): none for seven (5/5), some verbal reassurance for ID14 (4/5), and moderate for ID16 (3/5). Most children were confident (Q12): five entirely (5/5) and two nearly entirely (4/5). ID6 easily explored but no rating was given. Yet, ID9 was scared (1/5), but practitioners said that she expected to be scared when entering. Moreover, she may have been distressed due to feeling watched,

and to not controlling the environment due to the spectator condition. Eight children very easily used the system (Q13-5/5), and ID16 easily used it (4/5). Moreover, ID1 was "immersed and discovered everything alone", and ID8 "did not move but everything was at arm length". At the end, apart from ID9, most children interacted well (Q14): totally for seven (5/5), or well for ID7 (4/5).

Agency Most children who wore the HMD could identify the stimuli (Q16): five with great ease (7/7), and ID1 (6/7) and ID16 (5/7) with ease. In particular, ID6 actively switch off the music when wanting to. Though, practitioners were unsure about ID4's ability to identify stimuli (3.5/7), as focusing a lot on the music and not exploring much. No answer was provided for ID9 who got worried.

Engagement Apart from the ID9 who got worried, most children had fun (Q23): seven a lot (7/7) and ID4 nearly a lot (6/7). ID1 was not amused but relaxed (4/7). About involvement (Q24), apart from ID9 (3/7), most children were involved, whether entirely for seven (7/7) or nearly entirely (6/7).

Social Interaction Most children communicated with the adults (Q25): five a lot (5/5) (including ID17 who wore the HMD for a short time), and three moderately (4/5). In particular, ID4 interacted more than usual with people around (e.g., practitioners were struck when she asked them to dance together). ID14 also initiated shared play by giving the HMD to the practitioners. Moreover, ID17 communicated through the monitor while the practitioner was wearing the HMD. At last, ID1 (3/5) and ID6 (2.5/5) also communicated but non-verbally, maybe because not hearing well what practitioners said with the HMD.

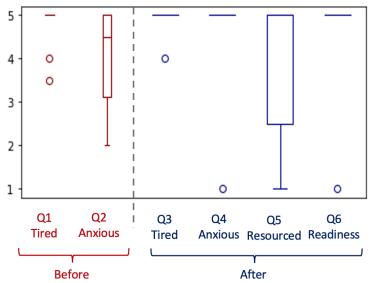

Fig. 3. Questionnaires' answers about children's state. Bars represent the median, rectangles represent the interquartile range (IQR) (50% of the sample's values), and circles represent outliers. **(A)**. Evolution of tiredness and anxiousness between the beginning and the end., **(B)** Being resourced at the end and ready to start another activity.

Evolution of the child's state When starting, all children were in a good physical state, apart from ID17 who was tired (Q1-4/5) and ID9 (Q1-2.5/5). Six children were not anxious (Q2): five not at all (5/5) and ID17 slightly (4/5). Yet, four children were a bit worried: ID16 asked what would happen (3.5/5), ID6 if "it was a trap" (3/5), ID14 displayed apprehension (2.5/5), and ID9 asked if practitioners would "frighten her" (2/5). At the end, no child was tired (Q3-5/5), and nine children were not anxious (Q4-5/5). Hence, four children got secure (ID6, ID14, ID16, ID17). Yet, ID9 got scared (1/5) due to acceptability issues: running out of the room and throwing the HMD. Six children got resourced (Q5-5/5), and two were as before (2.5/5). Practitioners highlighted that ID7 got calmer even if anxious the day before. At last, apart from ID9 (1/5), most children were ready to start another activity when leaving (Q6): seven entirely (5/5), and two with no answer (indicating no detrimental effects).

Critical incidents Psychologists mitigated the fact that ID9 ran out by evoking her condition and impulsiveness. Although ID6 was slightly worried when starting, he asked to come back every week. This request is uncommon for him and accounts for his engagement. ID7 could "unload" when playing while being in control (see Figure 5B), which is uncommon for him. ID7, ID14 and ID17, socially interacted more than usual: ID7 kept eye contact with the adults, ID14 initiated shared play by giving them the HMD (see Figure 5E), and ID17 interacted threw the screen. At last, ID14 went on the floor when first wearing the HMD, and ID5 stepped over the column's border to go inside it (see Figure 5D).

3.2 Findings from the Interviews, Notes, and Observations

Findings coming from the deductive content analysis are first presented. Then, three categories that were built through the inductive content analysis are presented: *Real vs. Virtual*, *Exploration of the Body and Space*, and *New Hypothesis*.

Acceptability All children could wear the HMD with practitioners' support. Only ID9 got very anxious, and quickly asked to stop. However, she was already anxious when entering the room. Four children perceived a slight discomfort, due to the HMD being too tight, heavy, or to feeling hot. Half of the children emphasized the institutional aspect, asking questions about the other children who participated. Five children described their experience as "weird" but pleasant. Yet, some children displayed some apprehension: three children only interacted "at arm length", not daring to move too much, and two children asked the practitioners to wear the HMD before them for reassurance. Doing so, they observed the practitioners while looking at what they saw through the monitor.

Usability Eight children easily used the equipment. For instance, ID1 was "immersed and discovered everything alone". Yet, ID14 and ID16 required a lot of guidance. As psychologists said: "We proposed her [ID14] to stand up [...].

Then she held Olivier's arm [one practitioner] to move in space, with still some difficulties", or "I made her [ID16] try things". ID16 verbally confirmed that she preferred to explore with Olivier, and even drew herself next to him (see Figure 4). Children were not bothered by some bugs that happened, even if possibly slowing down their discovery process. The microphone bubble was hard to use, as requiring to perform two actions (touch then speak). Eight children respected the limits of the AR space, and two went beyond to observe the limits of the real room. Five children understood that the vibrations came from the controllers. ID4 could explore alone although she is usually very passive.

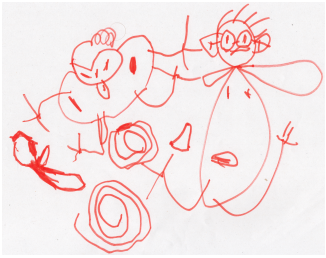

Fig. 4. Drawing that ID16 made, representing herself next to the practitioner.

Agency While three children enjoyed the controllers' vibrations, other children were more interested in the audiovisual stimuli. Three children particularly enjoyed one stimulus: the bubble column (ID1), the music (ID4), and the music panel (ID7). They seemed to use it to: get secure, and/or to refocus on their body experiences after exploring. All children looked at their bodies (mainly their hands) and eight children went through virtual elements with their head and hands to see them disappear.

Engagement Eight children were involved and enjoyed the experience. For instance, ID7 sang, laughed, or danced while touching the virtual panels, although being in a bad state the day before according to the practitioners. These children focused on their inner experiences (little social interaction), which is a significant clinical finding according to practitioners. Seven children verbally expressed their joy, asking to come back the week after. Surprisingly, ID1 said that he had fun, but that he did not want to come back the week after. ID9 expressed anxiety.

Social Interaction All children interacted with the adults, but eight had inner experiences. Indeed, these eight children mainly asked questions when requiring support or answered practitioners' questions. Yet, some of them included practitioners in their experience: ID1 pointed at them with the controllers, or ID8

described everything aloud. At last, two children were more interested in the other rather than in technology (ID4, ID17). In particular, ID17 interacted with practitioners through the screen, and ID14 interacted "without disappearing in the relationship with the adult", which is uncommon for her.

Evolution of the child's state Practitioners did not comment on this evolution, except for ID9 who got worried. Yet, they highlighted that the setting was *holding* for four children. This clinical concept is used to describe a supportive environment for generating and supporting interactions between the child and the practitioner [41]. Indeed, these four children got more secure than usual: ID1 got very calm, ID4 got calm even if several adults surrounded her, ID7 kept in control while being excited, and ID14 could socially interact.

Real versus Virtual Five children questioned the differences between real and virtual. They asked if the physical elements in the room were real, and if the virtual elements could have an impact on the adults being in the room. Three children also experienced a possible feeling of presence, i.e., feeling of being here. Indeed, ID8 asked if the water from the column could go over the floor, ID6 hit the ponds with his feet (see Figure 5A), and ID5 stepped over the border of the column (see Figure 5D).

Exploration of the body and space Seven children performed gentler gestures than usual, and three children mainly focused on one stimulus. Children focused on their body image: all looked at their hands, ID4 asked to look at herself in the mirror, ID5 asked to be photographed, and ID16 drew herself with the practitioner on her side. Five children made uncommon movements: softer, more hesitant, or, conversely, dancing more for ID16. Four children adopted a different gait. Indeed, three of them lied on the floor: ID4 possibly due to anxiety, while the two others may have done it to calmly explore their body and the AR space. Moreover, ID5 behaved like a robot when entering and leaving.

New Hypothesis Practitioners raised four new hypothesis about using AR for children with neurodevelopmental disorders and associated ID. First, HMD could help to make longer eye contacts. This was raised after ID6 made long eye contacts. Second, AR could help to better understand the others' mental states, by perceiving through the monitor the practitioner's AR view. Indeed, ID17 could understand that the screen represented the practitioner' view. Third, AR could enhance body awareness. Indeed, ID14 and ID16 socially interacted without "disappearing", although uncommon for them. At that, adjusting the proportion between virtual and real elements could prompt reassurance, especially regarding the body presence of the others. This was raised after ID7 kept in control while being excited, although uncommon for him.

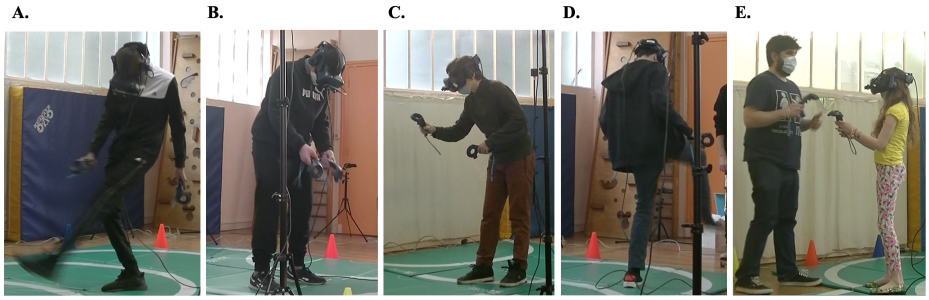

Fig. 5. Photographs of critical incidents for four children, (A) ID6 hitting a pond with his foot, (B) ID7 unloading on the music panel while keeping in control, (C) ID8 trying to write his name on the drawing panel, (D) ID5 stepping over the border of the column, (E) ID14 giving the controller to the practitioner after proposing him to test the HMD.

4 Discussion

This paper explored the use of the HMD-based AR environment *Magic Bubbles* in a day hospital setting with ten children with autism and HS, or neurodevelopmental disorders and associated ID. As little was known so far about how these children would react when exposed to HMD-based VR/AR [7, 10, 24, 36], the paper has four main contributions. Three correspond to the three research questions, about acceptability and usability (RQ1), engagement (RQ2), and reassurance (RQ3), and one appeared from the data analysis process. First, most children displayed positive acceptability and usability (RQ1). The inductive analysis process also showed that children explored two aspects in addition to the virtual interactions: the difference between real and virtual elements and the shift in their self perception. Second, children were engaged with an inner experience, but still communicated (RQ2). Third, apart from ID9 who experienced cybersickness, four children got more secure, and the others were in the same state after than before the experience (RQ3). At last, four new hypothesis emerged in relation to practitioners' concerns which deserve future investigation. The validation of the three research questions prompt to conduct future testings with *Magic Bubbles* during a longer period with autistic children with HS. After presenting the findings related to the three research questions, limitations and future perspectives are drawn, which include the new hypothesis that emerged.

4.1 Accepting and Using *Magic Bubbles*

All children accepted to wear the HMD, as in previous VR [15, 29] and AR [2] studies. To that end, they required practitioners' support. For instance, two children asked practitioners to wear the HMD before them for reassurance, as in Garzotto et al. [15]'s study where two out of five children made the same request. In our study, three children experienced discomfort, including cybersickness for

one of them. This finding echoes Newbutt et al. [29]'s findings, where four out of twenty-nine participants felt unwell and had to stop. In our study, despite their ID and limited verbal abilities, most children could express when feeling unwell. Though, they could hardly express if the HMD was correctly adjusted. This finding calls for devising future protocols to minimize potential adverse affects with HMDs for autistic children with HS, thus complementing Schmidt et al. [36]'s process-model that was mainly designed for autism with LS. At last, the methods for measuring acceptability through caregivers vary between previous studies [2, 15], and between our study and previous studies, thus making definitions of acceptability to vary. To make sure that we actually measured acceptability features and not other features (e.g., engagement), future research should focus on designing new standardized acceptability and usability measures for children with neurodevelopmental disorders and ID that would allow to collect their views.

Most children easily used *Magic Bubbles*, apart from ID9 due to acceptability issues and ID17 who wore the HMD for a very short time. *Magic Bubbles* was well adapted with respect to children's sensorimotor and understanding abilities. For instance, despite understanding difficulties, ID7 could explore and have fun. Then, practitioners supported children during their discovery, as in [2, 15]. Guidance was individualized, and ranged from low levels (e.g., for ID1) to moderate levels (e.g., ID16 needed physical guidance). Our positive acceptability and usability findings complement the findings from previous HMD-based studies conducted with autistic individuals with HS [2, 15, 29].

Children explored three main aspects: virtual interactions, real versus virtual elements, and self perception. First, they explored the virtual interactions alone or with practitioners' support. To do so, they often displayed uncommon behaviours: seven used gentler gestures than usual, and three mainly focused on one stimulus. This insight calls for more research to better understand these behaviours. In particular, focusing on one stimulus may be linked with self-regulation strategies during the discovery process (to not get overwhelmed by too many information). Hence, parallels could be drawn with VR/AR derivatives of repetitive behaviours that children often use to get resourced, that previous research already suggested to investigate [6]. Gentler behaviours may also be linked with a shift in their self perception. Second, children used various strategies to understand the difference between real and virtual elements. Future research should examine their understanding of real versus virtual, with respect to these various strategies and children's profiles. At last, children were highly interested in their self perception (e.g., looking at their hands). This unexpected insight accounts for a shift in self perception that deserves more investigation.

4.2 Communicating with practitioners

All children socially interacted with the adults. Yet, most of them displayed inner experiences. For instance, ID1 and ID6 mainly communicated non-verbally, possibly to remain in the virtual environment (ID1, ID6), or "to benefit from the effect of immersion", as practitioners said (ID1). Moreover, three children

displayed unusual social interaction behaviors. First, ID4 and ID17 were more interested in the other than in technology (e.g., ID4 communicated more than usual). Then, ID14 socially interacted without "disappearing" and drew herself next to a practitioner (see Figure 4). These experiences highlight the social interaction potential of *Magic Bubbles*, when used with practitioners in a clinical setting. This finding contradicts potential AR risks of isolation [7], that practitioners can be afraid of when working with autistic children with HS [5].

4.3 Getting resourced

All children who wore the HMD were engaged, apart from ID9 due to acceptability issues. Most children had fun, and ID1 got relaxed. These findings confirm the positive results that were observed in previous HMD-based VR [29] and AR [2] studies. In our study, seven children also asked to come back the week after. Two children displayed unexpected behaviours accounting for their engagement: ID14 drew the shared experience and ID16 danced a lot. Moreover, *Magic Bubbles* enabled ID4 to be resourced enough to communicate. Furthermore, children who were engaged were still in control of their actions. In particular, ID7 could "unload" without being over-aroused, which is unusual for him. Hence, practitioners said that *Magic Bubbles* was *holding* [41], i.e., a supportive environment for generating and supporting interactions between the child and the practitioner. Indeed, four children got more secure. Thus, such HMD-based AR approaches are promising to complement clinical interventions for children with HS. At last, since some children felt immersed, future studies should examine if reinforcing the feeling of immersion could also reinforce this *holding* potential.

4.4 Limitations and Future Perspectives

As this field study was conducted in a clinical setting, the environment could not be entirely controlled which limits the generalization of the findings. For instance, children's behaviours may have been influenced by external noise (children shouting in the corridors). Yet, conducting the same experience in a laboratory setting would be impossible, as changing children's environment could disturb them and induce anxiety [6]. Hence, new methods must be devised to guarantee the ecological validity of AR autism research, by conducting field studies in clinical settings while precisely controlling specific environmental aspects. To that end, some implicit measures could be used if relevant for the study and the children (e.g., number of interactions). Moreover, physiological data could also be used (e.g., skin conductance) if the clinical team and/or children's relatives deemed that biosensors could be well accepted, even if in our study the psychologists thought that they would not have been accepted by these children. In that case, analyzing physiological data would require to compare it with psychologists' insights, so that to understand the parameters being representative of children's behaviours. Although this approach remains under-used in AR/VR studies [18], it represents promising research avenues [39]. The second limitation is due to the fact that the results mainly account for practitioners' perspective. Indeed,

children's limited verbal abilities prevented from directly getting their views, despite efforts that were made (e.g., using drawings). Future research should further investigate how to collect the perspective of autistic children with HS, by devising methodologies as previously proposed by Spiel et al. [40].

Four hypothesis emerged that deserve more investigation. First, HMD could allow children with neurodevelopmental disorders and associated ID to make longer eye contacts, as not direct but mediated through AR. Second, AR could prompt the understanding of the others' mental states for autistic children with HS, by perceiving through the monitor the practitioner's AR view. Third, AR could enhance body awareness for children with neurodevelopmental and associated ID. Fourth, adjusting and individualizing the proportion between virtual and real elements, in particular regarding the body presence of others, could prompt reassurance for these children. This fourth hypothesis extends the findings from previous studies, suggesting to first work in VR and then go to AR, so that to gradually fade prompts while encouraging the generalization of the skills learned [6]. Moreover, creating use cases as proposed in the last hypothesis could also help to test the other hypothesis.

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