Virtual Reality and Autism Spectrum Disorder: Emergence of Sensory-Motor and Olfactory Potentialities in an Anthropocentric Epistemological Approach

Cécile Lacôte-Coquereau[1] [a], Paul Richard[2] [b], Emmanuelle Richard[2] [c] and Patrice Bourdon[1] [d]

[1]*Centre de Recherche en Education de Nantes, Nantes University, Chemin de la Censive du Tertre, Nantes, France*

[2]*LARIS – SFR MATHSTIC, University of Angers, 62 Av. Notre Dame du Lac, Angers, France*

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Abstract: The work presented in this paper is part of an innovative program including researchers from computer science, psychology, and education science. The aim is to propose immersive virtual environments to develop autonomy skills of young adults with autism having specific visual, psycho-sensorial, and cognitive capabilities. Several skills towards a progressive autonomy are thus targeted: interactions and social skills, verbal or alternative communication, perception-action coupling, and joint attention. In this context, a virtual supermarket has been developed, allowing participants to be confronted with shopping activity.

1 INTRODUCTION

Since the dawn of the 21st century, in the hope of alleviating cognitive dysfunction, researchers, and therapists have been seizing the potential offered by virtual reality (VR) (Fallet et al., 2022). Despite the abundance of literature cross-referencing autism spectrum disorder (ASD) and VR, there is a dearth of work addressing this atypical triple comorbidity profile. This raises the question of the potential applications of VR in this ethical context: to what extent this technology may reduce the attentional and sensorimotor disorders of an autistic public with specific psycho-sensory percepts (Bogdashina, 2020; Mottron et al., 2006)? Our pioneering participatory research aims to support socio-educational strategies for a particularly vulnerable autistic population with intellectual development disorders (IDD), language development disorders (LDD) and sensory-motor disorders (WHO, 2022).

In the next section, we provide a brief overview of the use of VR techniques and recommendations for non-verbal or dyscommunicative autistic individuals. In Section 3, we describe our unique approach to the design of effective virtual environments (VEs) aimed at developing autonomy skills in young adults with autism who possess specific visual, psycho-sensorial, and cognitive capabilities. Section 4 presents and discuss some preliminary results. The paper concludes with a summary and introduces some future work.

2 PROPOSED APPROACH

2.1 User-Centred Design Methodology

VR technologies and 3D multimodal interaction techniques have been studied and used in the field of medicine and education for almost three decades (Burdea & Coiffet, 1994; Burdea et al., 1996; Popescu et al., 2002; Jankowski et al., 2013). In this context, olfactory feedback was used to increase the sense of presence in VEs and the memorization of information (Richard et al., 2006; Tijou 2007; Andonova et al., 2023; Cowan et al., 2023).

In the field of autism, recommendations support the importance of learning devices that are

[a] https://orcid.org/0009-0000-6976-6109
[b] https://orcid.org/0000-0001-9905-847X
[c] https://orcid.org/0000-0002-9592-6150
[d] https://orcid.org/0000-0001-9096-8872

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intrinsically centred on users, to enter affordance (Gibson, 1977) with their cognitive percepts. In this context, we propose an epistemological, anthropocentric approach (Fuchs, 2016) that is part of innovative participatory research in which the psycho-sensory specificities of users are integrated into the process of designing VEs (Lacôte-Coquereau, 2023).

Appropriate to autism, the User-Centred Design methodological approach (Guffroy et al., 2017) is part of the subject-participant concept (Bourdon, 2021). The participation of users, who become co-creators during the innovation design and implementation processes, is a key point of the proposed methodology. We can then, via this systemic approach, design, prototype, test and improve the VE (Renaud & Cherruault-Anouge, 2018).

The design process took place directly in the living environment (specialised medico-educational home) and with the autistic people concerned (Figure 1). The process started in June 2021 with the introduction of immersive VR to the participants, researchers, and the socio-educational team members engaged in the project. The initiation involved the exploration of the Antarctic National Geographic VR application. Throughout this initial phase, spanning several months, we were able to discern the interests of autistic users in VR, recognize their sensitivities, assess their motor and cognitive limitations, and gauge their potential. This evaluation was grounded in the diagnostic assessments specifically designed for autism spectrum disorder (ASD).

Following the initial phase of immersion and acclimatization, the experiment commenced with young adults diagnosed with autism spectrum disorder (ASD). Adjustments and enhancements to the virtual environment (VE) were carried out based on feedback from participants, considering the responses and reactions of both the autistic individuals involved and the medical team that supports them daily. The VE was also refined and adapted according to the specific psycho-sensory specificities of the participants, enriched by brainstorming and design thinking sessions and design thinking sessions with the entire socio-educational team and the researchers (Renaud & Cherruault-Anouge, 2018).

During the design process, the VE was adjusted after each trial according to the difficulties observed by the medical-educational team or the observations of the participants. These modifications included a reduction in light intensity (visual hypersensitivity), an increase in olfactory stimuli, and the addition of certain pictograms to make it easier to understand the interaction possibilities. The equipment was also modified to facilitate observation of the VE, for example by replacing a fixed chair with a swivel chair.

(a) (b) (c) (d)

Figure 1: Illustration of the User-Centred Design process: young adults with ASD, researchers, and socio-educational team first immersion in the Antarctic application (a, b, c), and experiment with the young adults with ASD (d).

2.2 Participants

The study involves a vulnerable population, benefiting from a legal protection measures, due to impaired cognitive, relational, or physical faculties. The cohort is made up of 8 young adults with autism spectrum disorder (ASD), language impairment and Intellectual Development Disorder / IDD (WHO, 2022):

- 4 men - 4 women
- Average age: 23
- 6 out of 8 subjects have no access to writing or reading
- 8 out of 8 have impaired oral language skills

Clinical assessments were based on the international diagnostic scale AMSE - Autism Mental Status Exam (Grodberg et al., 2014). Seven significant ASD items are rated from 0 to 2, depending on the severity of the impairments: eye contact, interest in others, pointing ability, language, language pragmatics, stereotypies, intrusive preoccupations. The average score for the group (1.6/2) indicates moderate to severe language impairment. On the other hand, the evaluations show a relatively preserved pointing ability (group average: 0.3/2). In this sense, the ray-casting metaphor, which can support alternative communication, seems to us to be a major support provided by the VE.

2.3 Task Description

A meta Quest 2 headset was used to immerse the participants in the virtual supermarket. The task asked of the participants was as follows. They had to collect different products from the shelves in a basket, according to their wishes, in order to enable self-determination. Given their sensory-motor difficulties,

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the proposed navigation technique was teleportation. A guide-experimenter pressed a key on the keyboard to teleport the participants from point to point in the shop: bakery, fishmonger, fruit, flowers, bookshop. The participants had to point with their hands at the objects to be collected. A ray (ray-casting), which did not require verbalisation, was then used to select the objects to be collected. The item was directly placed into the basket, until the checkout.

A garden, designed as a sensory resting place was proposed to give each user a cognitive break. An avatar, designed to resemble the physiognomy of the educational team co-ordinator, was also implemented to enable users to ask for help, also using the hand-free ray casting technique, if they felt the need during the task. The participant's ability to social interaction and self-determination of the subject-participant were thus and enhanced.

3 VIRTUAL ENVIRONMENT

3.1 Visual/ Acoustic Affordance Design

Autism Spectrum Disorders (ASD) are characterized by impaired communication and social interaction, sensory atypia, stereotyped behaviours, and restricted interests, sometimes making engagement in cognitive activities complex (WHO, 2022). Thus, for people with autism, digital tools can arouse a particular interest, conducive to learning (Mercier et al., 2022). In this context, VR seems very appropriate as it is part of an environment designed in affordance, in line with users' emerging abilities (Gibson, 1977). Affordance is that space-time of possibilities, the result of a relationship between two entities. In VR, this induces the anthropocentric conception of a secure, iterative, and gradual space, qualitatively and quantitatively controlling the information delivered by the system (Klinger, 2014). In this sense, VR facilitates individualized consideration of the autistic person's specific sensory perceptions, prevailing over exogenous stimuli (Zhao et al., 2022).

In our everyday world, the perceptual-motor and perceptual-cognitive systems of people with ASD are overwhelmed by a noisy, overly rapid flow of information (Chokron et al., 2020; Swart, 2006). In contrast, VR can offer a stable, reproducible learning context, free from exogenous distractors (noise, comings and goings, unexpected intrusions, etc.), all of which are deleterious to concentration and attention. By minimizing the intensity of acoustic and visual flows (Mottron et al., 2007), slowing down images and speech flow, immersive technologies promote a reduction in behavioral disorders, subjective well-being (Lacôte-Coquereau, Vigier, et al., 2023) and, subsequently, an availability conducive to learning (Tardif et al., 2017).

3.2 Ray-Casting: Supporting Executive and Language Functions

Cognitively, ASD impacts executive functions: planning, memorization, inhibition, attention (Klinger, 2014). Often targeted in the field of autism, joint attention deficit profoundly affects social cognition (Baron-Cohen et al., 1997). In VR, this essential skill can receive special support. In dyscommunicative subjects, the design of interaction metaphors based on the pointing gesture, such as ray-casting (Baloup et al., 2019), appears to be able to support attentional skills (Jordan, 2004).

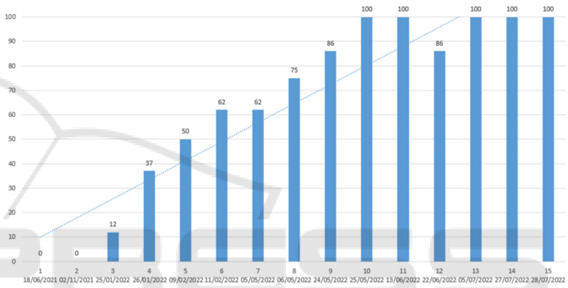

Figure 2: Evolution of the success rate of pointing gestures over the first 13 months.

A precursor to pointing and intentionality, joint attention can be defined as preverbal communication (Aubineau et al., 2015). It is the key interaction for social development (Mundy & Newell, 2007). Its mastery is therefore essential to the psycho-cognitive development of dyscommunicative subjects. The implementation of this pointing (ray-casting) technique proved to be relevant in three ways: reinforcing intersubjective attention, substituting for absent or defective verbalization, and supporting impaired motor functions (Figure 2).

3.3 Hands-Free Ray-Casting

Motor stereotypies are frequent hyperkinetic disorders (Goldman et al., 2009), whose main characteristics are that they are involuntary, predictable, rhythmic, and repetitive. In the case of motor stereotypies typical of ASD (flapping or elevated hand tremors), it is now possible to filter data from localization sensors to stabilize these actions by motor-behavioral software aids (Fuchs, 2016) and improve interaction (Sakkalis et al., 2022). Immersive ray-casting techniques can also be used with the hand-tracking approach. In this way, the technique efficiently replaces the use of 3D controllers, joysticks or buttons that are too complex for people with intellectual development and motor coordination difficulties.

(a)

(b)

Figure 3: Self-determined avatars in the virtual shop: virtual educator (a), and the cashier (b).

3.4 Social Presence

On a societal scale, social interactions "enable us to construct representations that are indispensable to our understanding of others and the world" (Aubineau et al., 2015). However, these fundamental skills in society give rise to real difficulties for subjects with autism. Yet "the experience of self can be enhanced if other beings exist in the virtual world" (Biocca et al., 2003). Showing "appearances of human faces or forms plays an essential role in the symbolism of a representative scene" (Willumeit et al., 2022). Thus, envisaged as scaffolding for social interactions hampered by ASD, "avatars and virtual elements contribute to training in the recognition of facial expressions and bodily gestures" (Mesa-Gresa et al., 2018). Several avatars, chosen by the autistic users themselves in self-determination, were thus added to the VE. The aim here is to reinforce the feeling of "social presence" (Biocca et al., 2003), in a reassuring context conducive to learning (Figures 3a and 3b).

4 RESULTS AND DISCUSSION

The results of the study confirm that VR techniques with an anthropocentric focus can promote activity engagement and learning in dyscommunicative autistic people (Lacôte-Coquereau et al., 2023). The results also underline the importance of a VE designed in affordance with the psycho-sensory needs of learners to increase their cognitive availability and, subsequently, their learning. A major question remains, however, as to the generalizability of this immersive protocol: how can we involve autistic users who have little or no willingness to experiment with the VR headset? Faced with this motivational fragility, we felt it was essential to heuristically investigate the restricted interests and particular sensorialities of each subject, in an ethic respectful of human diversity.

4.1 Sensory Feedback: A Memetic and Cognitive Vector?

Among the sensory modalities offered by VR, one of the avenues currently under study applies to the olfactory domain, a sensory-cognitive channel now integrated into the headset during immersive trials. Retro-olfaction, evident from the moment a child is born (Candau, 2000), is a physiological mechanism that enables the olfactory system to perceive aromatic characteristics. Research into the neurophysiology of olfaction suggests that depriving ourselves of the powerful emotional tone of odors would mean "cutting ourselves off from an essential link with the world" (Holley, 1999).

At the memetic and cognitive levels, olfactory impressions, "individual symbols par excellence", convey "the capacity to evoke memories and feelings removed from social communication" (Sperber, 1974, p. 130). According to the work of André Holley, the olfactory channel may have two dimensions: a "cognitive dimension" driven by olfactory signals, and a "motivational dimension of sensory stimuli" (Holley, 1999; Washburn, et al., 2003; Richard et al. 2006; Tijou, 2007).

4.2 Sensory Feedback: A Personalized Motivational Vector?

During the VR trials, the orthonasal route was implemented, inspiring the scent directly from cartridges integrated into the VR headset. Following the anthropocentric participatory approach, several cartridges were selected in accordance with users' wishes. As users stroll through the virtual

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supermarket, they synchronously diffuse a fragrance corresponding to the food on the shelves, encouraging visual identification and olfactory stimulation: coffee, chocolate, apple, orange.

Diagnostic assessments carried out beforehand with autistic people highlight an olfactory hypo-hyper-sensitivity (Bogdashina, 2020; Degenne-Richard, 2014): "R 7 agrees to smell the scented cups. Her inspiration is deep and fresh. On two occasions she was able to differentiate between sweet and salty smells. ... was able to say that she doesn't like the smell of fire" "R4 looks for strong smells". In keeping with these sensory specificities, the choice of scents was closely linked to the interests and tastes of the autistic people: a major appetite for apples for one, chocolate for another. On the other hand, an olfactory surplus could prove repellent to a subject with olfactory hypersensitivity or who rejects one of the scents inhaled. A detailed knowledge of the user's sensory specificities is therefore essential in this field of experimentation.

Professionals and scientists attest that, in the field of autism, "personalization according to centers of interest is a prerequisite for arousing interest" and enhancing an often-random engagement in learning activities (Renaud & Cherruault-Anouge, 2018, p. 140). Thus, it seems relevant to us to mobilize "different sensory modalities" (Vandromme, 2018, p. 18) to elicit greater immersive interaction. Philosophers and anthropologists have stressed the importance for perceptual awareness of combining signals transmitted by different sensory pathways (Cassirer, 1972; Lévi-Strauss, 1964). At the end of the first experiments, users' verbatims, facial expressions and gestures revealed sensations of pleasure when scent was diffused (Figure 4).

4.2.1 Olfactory Test R1

R1 - "I smelled...it smells like coffee, it's nice...it makes me want to... Apple, yeah, it's good" (smile and thumbs up).. " Orange, it smells good... it's good, it makes me want to go shopping.

GP - Do you remember the smells of the helmet?

R1 - Yes, chocolate and coffee

GP - And the fruit?

R1 - Apple, orange

Olfactory feedback supports the correlation towards the subject's ability to memorize, evoking pleasure, and thus developing motives for activity (Leontiev, 1975).

Figure 4: User's deictic gesture of assent to olfactory diffusion during a trial.

4.2.2 Scent Test R2 (Non-Verbal)

During another trial in the virtual supermarket, the professional guide offers R2 (non-verbalizing subject) an olfactory diffusion of chocolate (a scent that R2 particularly likes):

GP - "Would you like some chocolate now?

R2 - Mmm (nodding, agreeing)

GP - It's going to smell like chocolate now.
(new diffusion of chocolate scent)

R2 - (pause for scent diffusion) R2 concentrated.

No rictus, no postural retreat during retro-olfaction). With a pointing gesture via ray-casting, R2 selects the chocolate box of her choice from the shelf. She laughs and applauds loudly" (Figure. 5). For participant R2, a non-verbalizer, olfactory diffusion induced increased thinking time, concentration, and visual attention, culminating in an autonomous choice of the chosen food product (chocolate), by ray-casting. "All sensory stimuli are tangled and interchangeable dialects of the universal language of perception" (Steiner, 1967). Ultimately, while the current results are promising and encouraging, it will now be a matter of replicating and refining the innovative immersive approach using olfactory modality, with a broader corpus. The anthropological evidence (Passeron & Revel, 2005) from this participatory research is based on a quantitatively small cohort (8 adults with ASD), which does not allow for convincing generalization. However, for Passeron and Revel (2005), "even in a single individual, we can solidify hypotheses on the basis of recurring clues". Although this case is singular, it reveals a new reflexive space. As such, it is highly

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relevant, and can be tested in other scientific, therapeutic, or educational contexts.

Figure 5: Ray-casting of chocolate by R2 after retro-olfaction.

5 CONCLUSION AND FUTURE WORK

The work presented in this paper aims to design immersive VEs to develop autonomy skills of young adults with autism having specific visual, psycho-sensorial, and cognitive capabilities. Several skills towards a progressive autonomy are targeted: interactions and social skills, verbal or alternative communication, perception-action coupling, and joint attention. In this context, a specific user-cent red design methodology is proposed. A virtual supermarket, with the integration of olfactory feedback, has been developed allowing participants to be confronted with shopping activity and the development of this skill. Results showed that VR with an anthropocentric focus can promote activity engagement and learning in dyscommunicative autistic people. The results also highlight the need to design and offer immersive environments specifically tailored to the psycho-sensory needs of the end users, in this case young adults with autism. To extend and validate our approach, we plan to design other virtual environments such as a city and a flat. We will also be proposing and comparing other navigation techniques, such as free teleportation and step-in-place, to favor users' autonomy.

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