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L'utilizzo di informazioni visive e propriocettive nella Realtà Virtuale: differenze evolutive tra disturbi dello spettro autistico e sviluppo tipico.

Utilising Vision and Proprioception In Virtual Reality: Developmental Differences Between Autism Spectrum Disorder and Typical Development.

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Introduction

The present study aims to explore potential and limitations of the use of Immersive Virtual Reality (IVR) as a tool in developmental psychology research, clinical assessment and intervention. Talking about IVR, one of the main issue is the way in which this technology involves the user's senses and affects his/her motor actions. Literature has long been neglecting the study of how IVR can function in relation to the user's individual psychophysical status. We will go further into the discussion of the need to conceive IVR as a tool with particular features, which can differently interact with individual sensory, motor and cognitive functioning. In particular, this study examines aspects related to the user's age and developmental trajectories. We will compare adults and children with a typical or atypical development, in their sensory and motor functioning, in reality and IVR. With regard to the atypical population, this study is about Autism Spectrum Disorder (ASD), which is a neurodevelopmental disorder that hugely concerns sensory and motor atypicalities. Research and policies are recently focusing on IVR as a promising tool for ASD. An increasing number of studies is providing evidences for the beneficial effects of IVR stimulation for people with ASD. However, little is known about the factors underlying IVR vs real stimulations efficacy. This study aims to provide evidences about which IVR features can suit and improve the particular sensory functioning of this clinical population.

1. Multisensory development

From the intrauterine life, our physical, psychological and social development makes progresses thanks to the interaction between our genetic profile and the environment. Information from the environment is detected by our emerging sensory functions. Sensory information comes from both the external world (*exteroception*) and the self (*interoception*). Interoception is the perception of our body and includes "temperature, pain, itch, tickle, sensual touch, muscular and visceral sensations, vasomotor flush, hunger, thirst" (Craig, 2002, pp.655) and so on. Exteroception processes information from the external world thanks to olfactory, taste, touch, auditory and visual systems (Damasio, & Carvalho, 2013). Information from these sensory modalities has to be integrated to interact with and learn from the environment. Developmental research on how people integrate this sensory information established some main core points (*ibidem*):

- Different sensory modalities provide complementary sensory information
- At different ages, people rely on the various sensory modalities differently

- Multisensory integration takes time to develop and emerges in a heterochronous pattern
- Crossmodal calibration: one accurate sensory modality can improve performances essentially based on information delivered by another, less accurate, sensory modality (e.g. vision improves motor performances based on proprioception).

Multisensory functioning is a core topic in developmental research regarding both typical and atypical development. In fact, multisensory atypicalities (usually named "impairments") similarly characterize different developmental disorders such as developmental coordination disorder (DCD), developmental dyslexia (DD) and autism spectrum disorder (ASD) (Hill, Crane, & Bremner, 2012).

1.1. Virtual reality: a tool in multisensory research

Virtual reality (VR) systems create simulations of reality, generally by providing computer-generated visual information but also sometimes integrating auditory, haptic, or other sensory information. The main area of VR that is increasingly receiving research interest and practice is Immersive Virtual Reality (IVR), where the stimuli have such high sensory fidelity that they block out the external world and fully engage the user (Bailey & Bailenson, 2017). IVR offers a lifelike experience including free movement, object manipulation, and social interaction. It primarily involves vision but sometimes even other sensory information. There is significant evidence that IVR is a useful tool for psychological research and therapy. Bohil, Alicea, and Biocca (2011) describe some of the advantages of using IVR in areas like social neuroscience, multisensory integration research, and spatial cognition and navigation research. The authors note that IVR allows for embodied naturalistic interaction which enhances ecological validity and allows for complete manipulation and instantaneous rearrangements of multimodal stimulus inputs. Beyond the huge amount of research regarding adult populations, researchers are also concentrating on the use of VR with children. A virtual environment can easily be designed such that each child's particular rehabilitation needs and learning style are taken into consideration. VR in general (immersive or not) has long been considered a useful tool for research with certain clinical populations, such as children with disabilities or Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD) (McComas, Pivik, Laflamme, 1998), obese children (Banos, Escobar, Cebolla, Guixeres, Alvarez Pitti, Lisón, & Botella, 2016) or children with other medical conditions (Won, Bailey, Bailenson, Tataru, Yoon, & Golianu, 2017). As regards IVR in particular, a recent work (Bailey & Bailenson, 2017) notes that this technology has been primarily used with children to achieve educational, pain distraction, and assessment purposes. However, there is a lack of evidence of its sensory effects, issues and benefits on child development, especially for pre-school children. Given the research gap concerning the use of IVR with children and its multisensory effects, the aim of the introductive part of this work is to examine the sensory mechanisms involved in interaction with IVR tools and environments.

1.2. Multisensory integration in IVR: vision and proprioception

Various senses can be manipulated using IVR. Most obviously, visual input can be manipulated by using a computer screen or head mounted display (HMD) to expose the user to a variety of visual stimuli and environments. The way in which the visual information is delivered, and its features, have a complex (usually unknown) effect on the sense of immersion, self-motion perception, and kinematics of movement (Powell & Stevens, 2013). It is important to consider factors such as display types, screen size, and field of view, the use of stereoscopic displays, visual content (peripheral cues, high-low visual contrast, etc.), calibration and scaling, static environment and dynamic environment changes.

It also seems that another of our most fundamental sensory perception, proprioception, could be manipulated in IVR. As the result of information from muscle and skin receptors, proprioception is the awareness of the position and movement of our body in space. It arises from static (position) and dynamic (movement) information, and is crucial to the production of coordinated movements (Pereira et al., 2014). In IVR, "the simultaneous experience of both virtual environment and real environment often leads to new or confounded perceptual experiences" (Gromala, Shaw, & Song, 2009, pp.71). For example, the user sees himself standing in the emptiness between two mountains but, instead of falling, he perceives the floor under his feet. Researchers mention that this can alter a user's body schema, body image, and even subtly affect one's sense of self. Similarly, Hayles (1992) describes how IVR modifies proprioception as users attempt to interact with the environment, for example, to grasp an object: "Proprioceptive sense flows out of the body to meet the artifact, but since there is no material object, it returns in a feedback loop that acts to dematerialize the body". Literature provides some examples of how IVR affects the user's motor activity by, it is speculated, influencing proprioception. IVR users are found to decrease their speed and took smaller steps while immersed in a virtual environment (VE) through a HMD compared to real life conditions (Mohler, Campos, Weyel, & Bülthoff, 2007). In addition, users seem to experience greater difficulties orienting themselves in VEs (Riecke & Wiener, 2007). Differences in biomechanics of walking, reduced field of view (FOV), and the differences in perception of distance in virtual worlds have been suggested to affect user's performance (Interrante et al. 2006, 2008; Loomis & Knapp, 2003; Renner et al. 2013).

As regards integration of vision and proprioception, it has been suggested that IVR spontaneously induces a sensory conflict between vision and proprioception. That could be responsible for the motion sickness that often occurs during IVR use (Onuki, Ono, & Kumazawa, 2017). The studies described above primarily tested adult populations, while there is a lack of studies regarding how IVR affects proprioception and its integration with vision in children, and the role of proprioception development and children's unisensory and multisensory processing skills. That is the reason why we need to conduct developmental research that compares subjects' motor performances at different ages and in real vs. virtual environments, when either visual or proprioceptive cues alone or both are present. To compare performances in reality and IVR, all the sensory conditions being equal, would clarify the role of both sensory manipulation and IVR per se.

1.2.1. Children population

There is a lack of studies about how IVR affects self-motion, proprioception and visuo-proprioceptive integration in children. While several studies have shown that proprioceptive competence is stably developed by 8 years of age (Sigmundsson, Whiting, & Loftesnes, 2000; von Hofsten & Rösblad, 1988), others have found improvements in positional accuracy continuing up to 24 years of age (Hearn, Crowe, & Keessen, 1989).

A recent study with children (8-12 years old) and adolescents (15-18 years old) provides some evidences about children's use of vision and proprioception to perform self-motion in IVR (Adams, Narasimham, Rieser, Creem-Regehr, Stefanucci, & Bodenheimer, 2018). The authors intentionally create a mismatch between visual (visual flow) and proprioceptive feedback (active motion) in different motor tasks. They measure children's ability to *recalibrate* (to adapt the motor actions to the provided abnormal visual input) and *re-adapt* to the normal characteristics of the real environment (post-exposure effects). As with adults in previous studies (Bodenheimer, Creem-Regehr, Stefanucci, Shemetova, & Thompson, 2017; Mohler, Thompson, Creem-Regehr, Willemsen, Pick Jr, & Rieser, 2007), children and adolescents show the ability to recalibrate in a few minutes. We would suggest that this could be seen as an indicator of motor learning through IVR. The authors find just one age-related difference, in regard to the rate of re-adaptation. Children re-adapt to the reality significantly slower than adolescents, demonstrating more pronounced post-exposure effects (the slower re-adaptation). Although the finding must be interpreted with caution, it could be a first proof of age-related differences in motor learning in IVR. Children's, more than adolescents', motor performances could be modified by the interaction with IVR environments. This could have meaningful implications for fields such as IVR rehabilitation, therapy, and education, suggesting that IVR interventions can be more effective early in life. The lack of research on the effects of IVR on infants and preschoolers excludes the possibility to highlight both benefits and risks at that age, to establish age-related limits and explore possible applications. Finally, research on age-related differences can identify design criteria to develop IVR tools for specific populations (Adams et al., 2018).

Petrini and colleagues (2016) used IVR to decouple visual information from self-motion and investigate whether adults and 10- and 11-year-old children can optimally integrate visual and self-motion cues. HMD was used to make participants learn a two-legged path either in darkness (active self-motion condition), or in a virtual room (visual + self-motion condition), or staying stationary while viewing a pre-recorded video of walking the path in the virtual room (visual condition). Participants then reproduced this path in darkness. The experiment, in contrast to what was expected, found that adults failed to optimally integrate visual and self-motion cues to improve path reproduction, however children did integrate the cues to improve their performance. The authors do not explain the results in terms of the possibility of IVR disrupting proprioception, and do not consider that IVR could have different effects on adults and children's performance. We could speculate that, if IVR causes some sort of conflict between vision and proprioception, adults' lack of multisensory integration in these environments could be due to their ability to ignore visual cues. Visual cues would be perceived as irrelevant for motor tasks, because they would be in conflict with proprioceptive information. Since this ability to ignore irrelevant visual cues seems not to be mature in children (Petrini et al., 2015), they could benefit from IVR motor training because they would still use vision to calibrate self-motion. Petrini and colleagues' (2016) findings essentially show that an HMD training (vision + self-motion) can be effective for children even if it is not for adults. Since findings in this area are still conflicting and unexplained, our study would aim to clarify how using an HMD can affects children's and adults' self-motion performance, and how these effects could be related to vision, proprioception, or visuo-proprioceptive integration in typical and atypical population.

1.3. Representation of the user's body in IVR

Studying the role of including a virtual body (VB) representation in VEs has long been considered an important issue in VR literature (Slater & Usoh, 1993). IVR environments make the user see him/herself from a first-person view and can include the presence of a graphical representation of the body at different levels of realism (Pan & Steed, 2017). Enhancing visual realism in VB representations could be important to induce realistic responses (Slater, Khanna, Mortensen, & Yu, 2009). A most recent work suggests that visuo-proprioceptive congruency could be more crucial than visual fidelity (Zopf, Polito, & Moore, 2018). With regard to the effects of a VB presence on motor performance, this aspect has not been greatly studied. A recent study suggests that the visual feedback provided by a self-avatar changes kinematics of gait (Côté, Charbonneau, Aissaoui, Nadeau, Duclos, Mezghani, & Labbé, 2017). However, this work has a small sample size, uses a less immersive display than HMDs, and considers only healthy adults. To contribute to the knowledge about these aspects, the present study aims to investigate the role of the absence of the body sight in self-motion performance.

1.4. Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder is a neurodevelopmental disorder which is characterized by persistent and pervasive deficits in social communication and social interaction, restricted, repetitive patterns of behaviours, interests, or activities. From a neuroconstructivist approach (Karmiloff-Smith, 1998), there is mounting interest in studying the early markers of Autism Spectrum Disorder (ASD).

1.4.1. Different motor development and motor deficits

Several possible predictors of autistic difficulties have been explored. The one we are interested in for our study's sake is the atypical path of motor development that seems to characterize high risk (HR) infants (Nickel, Thatcher, Keller, Wozniak, & Iverson, 2013). Movement impairment seems to be a general characteristic of the autism spectrum (Green, Charman, Pickles, Chandler, Loucas, Simonoff, & Baird, 2009). Posture development allows infants to interact, explore, and discover the physical and social world in more complex ways. In infants at heightened risk for ASD, the delay in posture advances can have cascading effects on cognitive and social skills. Motor impairments are characteristic of ASD across the lifespan, continuing into adolescence and adulthood (Travers, Powell, Klinger, & Klinger, 2013). Going backward to the low perceptual level underlying motor skills, some research explores the role on motor abilities of different sensory modalities (vision, proprioception, vestibular system), and multisensory integration. There are emerging evidences of multisensory deficits in people with ASD (Hill, et. al., 2012). It has been speculated that these impairments lead to an atypical use of unimodal (instead of multimodal) sensory strategies, with overreliance on a single sensory modality and decrease reliance on the others. When learning a new movement, there is evidence that children with ASD are less influenced by visual feedback (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009). Children with ASD show "an abnormal bias towards reliance on proprioceptive feedback from their own bodies, as opposed to visual feedback from the external world" (Izawa, Pekny, Marko, Haswell, Shadmehr & Mostofsky, 2012, pp.10). Proprioceptive bias versus reliance on visual information predicts impairments in motor control, social skills, and imitation ability (*ibidem*). A big study with children with ASD and neurotypical adults demonstrates, that postural instability is primarily evident when proprioception is disrupted (Minshew, Sung, Jones, & Furman, 2004). A recent study with 20 adults with ASD, shows that they have deficits in the use of vision to modulate proprioception. (Morris, S. L., Foster, C. J., Parsons, R., Falkmer, M., Falkmer, T., & Rosalie, S. M. 2015).

From an applied perspective, interventions could be aimed at increasing the reliance on vision in children with ASD, similar to what we have seen in TD children. Could this improve motor skills? Can we make children with ASD use other sensory modalities by confounding proprioception? Would IVR exposure be a useful training method to achieve this therapeutic purpose? If IVR does disrupt proprioception (Riecke et al., 2005), we should expect that children with ASD would benefit from interacting with immersive virtual environments where they could be trained to rely more on visual cues. These interactions should improve their motor learning, with resultant positive effects on motor, cognitive, and social skills.

1.4.2. Using VR in ASD research and intervention

In the case of Autism Spectrum Disorder, VR is particularly appropriate to allow for controllable input stimuli and monitor individuals' physical activities in a safe learning situation where assessment and training are possible even for children with language and communication difficulties (Strickland, 1998). VR allows researchers to achieve several aims: to study motor, cognitive, and social skills in this population, and to provide engaging training environments. In fact, it is possible to create non-invasive environments focused on the interaction between the child and the multisensory stimuli, giving the control of the VE to the user. Moreover, individuals with ASD, find computer technology highly motivating and rewarding (Parsons & Mitchell, 2002, Parés et al., 2005). Both non-immersive and immersive VR systems seem to be easily used by participants with ASD, and they effectively induce performance improvements (to see a review, refer to Bellani, Fornasari, Chittaro, & Brambilla, 2011). Given that motor difficulties and multisensory atypicalities are thought to be early markers of ASD, and IVR seems to change motor and multisensory dynamics, it is fundamental to see whether VR motor rehabilitation programs (VRR) and IVR multimodal stimulation are effective and why.

2. The present study

2.1. Research goals

The current study aims to:

1. Determine whether there are developmental differences related to the reliance on vision and proprioception and to visuo-proprioceptive integration.

2. Determine whether there are developmental differences between ASD and TD populations related to the reliance on vision and proprioception and to visuo-proprioceptive integration.
3. Explore whether IVR affects motor performance differently at different ages and in people with ASD.
4. Investigate to what extent IVR per se affects motor performance, and what is the role of the absence of a virtual representation of the user's body in IVR.

2.2. Method

2.2.1. Subjects

For this study, we planned to collect data from participants in 4 groups:

- TD children
- Children with ASD
- TD adults
- Adults with ASD

In the first phase of the experiment, we tested:

- 13 TD children: between the ages of 7 and 15 years (M_{age} = 10.5, SD = 2.8 years), 9 male and 4 female, without previous experience with HMD. They were recruited from two schools in Ruda (UD).
- 5 adults with ASD: between the ages of 21 and 39 years (M_{age} = 29.2, SD = 7.85 years), all male, without previous experience with HMD according to what has been reported by their psychologist. They were recruited from a residential clinic in Medea (GO). The clinic confirmed that they all have an ASD diagnosis. We did not establish inclusion-exclusion criteria based on IQs, verbal abilities, or other high-level cognitive functions.

In a within-subjects design, all participants are exposed to all conditions in randomized sequences.

2.2.2. Materials and set up

- Experimental room

We designed and built a room in which different sensory stimulations can be provided and the availability of vision and proprioception can be manipulated. The room is 2x2 meters, soundproof, made of wood panels, dismountable and transportable. It has black interior walls with white clouds randomly fixed on them. The same number of clouds is on each wall. The choice of clouds derives from the literature on the preference for geometric (Pierce, Conant, Hazin, Stoner, & Desmond, 2011) and cloudy visuals (Parés et al., 2005) in younger populations with ASD. The external walls are painted with a child-friendly sunny landscape which has been designed to encourage children to enter the room (Fig. 4).

Figure 1: Experimental room, external walls

In the middle of the room, we fixed a customized swivel office chair with a round base to the floor. The round base does not provide any proprioceptive or visual cues about the amount of turn the participant makes (Fig.5). A 360° protractor under the seat is visible via a dedicated camera which allows the measurement of the amount (degrees) of turn.

Figure 2: Experimental room, interior

- Illumination system:

One 50 cm white LED strip (12V DC, 24 Watt per meter), allows for a realistic and clear visual experience of the room.

One UV lamp (E27 26W) obscures every visual stimulus except for the white ones. With this light on, the white clouds on the walls are the only visual cues available.

One infrared LED spotlight (BIG BARGAIN BW103) allows us to capture video of the inside of the room even when it is completely in darkness.

This light system (UV lamp, UV attenuator, white LED strip, infrared LED spot), is anchored to the ceiling, over participants' heads, and is covered by a black panel which prevents participants from directly seeing the lights.

- VR provider

We provide the VR stimulation through a VR headset, or Head Mounted Display (HMD). We use the Oculus Gear VR 2016, 101° FOV, 345 g weight, interfaced with Samsung Galaxy S7,OS (operating system) ANDROID 8.0.0.

A NIKON camera KeyMission 360 has been used to make 360°pictures of the room and build the VR environments.

- Videotaping:

The room is monitored via one USB 2.0 DirectShow webcam, and one USB 2.0 DirectShow webcam with integrated infrared LED.

- Pc:

To monitor the video records and the VR stimulations, we use a SATELLITE Z30-B, Windows 10, 64bit , Intel Core i5-5200U CPU @ 2.20 Ghz,8,0 GB RAM, Intel HD Graphics 5500.

- Audio communication system:

The communication between people inside and outside the room is possible thanks to a system of USB speaker, microphone, headphones and one USB soundcard.

- Software:

We developed different software to manage the experiment. The VR server application is an Android application with VR environments, developed in Unity. The client interface is a remote interface to control the VR server application. It has been developed in Unity, for Windows or Android OS. A software for audio-video recording and real-time communication, has been developed in TouchDesigner.

2.2.3. Procedure

Participants are welcomed into the lab and are asked to sign a consent form. Parents of children and adults with ASD sign the form. The study has been approved by the local Ethics Committee of Psychology Research, University of Padua.

At least two experimenters conduct the experiment. Participants are asked to sit on the swivel chair which is fixed in the middle of the recording area inside the room. One experimenter closes the door and always stays inside near the participant. The second experimenter manages the experiment: he/she switches the lights on and off, changes the visual stimuli which are presented through the

HMD, and controls the video recording of the experiment. He/she is outside the room, giving verbal instructions to the first experimenter and to the participants through headphones and microphone. The first experimenter manages the passive-turn and remains silent behind the participants, providing no visual or auditory cues.

2.2.4. Experimental task

For each trial, the experimenter turns the chair a certain degree (passive turn) from a *start position* to an *end position*. After each passive-turn, participants are asked to turn back to the start position (active self-turn). Participants' stop position is recorded as the *return position*. The start position can change among trials because of spontaneous extra-task movements of the participant. This paradigm helps us avoid problems related to children's ability to understand verbal instructions such as "Turn 90 degrees." For each condition, the passive self-turn is done once to the right (clockwise) and once to the left (counterclockwise). For each condition, one passive turn is approximately 180 degrees and the other is approximately 90 degrees. All participants perform 12 trials across 6 conditions. During the passive turn, participants keep their feet on a footstool which rotates with the chair. In this way, they cannot make steps while being turned, and cannot count the same number of steps to make accurate active turns. To perform the active self-turn, participants can use their feet on the still platform under the chair to turn.

2.2.5. Measures of task performance

The accuracy of self-turn performances (turn accuracy) is calculated in terms of the difference between the *start position* (from which the experimenter starts the passive self-turn) and the *return position* (in which the participant stops the active self-turn). The turn accuracy is manually measured during an offline coding of the video recording. Two independent evaluators coded the videos and entered the start and return positions in the dataset. Values which would be divergent for more than 2 degrees are a priori considered disagreement values. A third coder examined the video records of the disagreement values to make the final decision. We evaluated the intercoder agreement by conducting the intra-class correlation (ICC), which is one of the most commonly-used statistics for assessing inter-rater reliability (IRR) for ratio variables (Hallgren, 2012).
From the dataset which combines the 2 coding, we obtained a final dataset with the average of the double values. On this final dataset, we carried out the data analysis.

2.2.6. Conditions

The order of conditions is randomized. Participants perform blocks of 2 trials per condition. We have 3 conditions in a real environment (R) and 3 conditions in a virtual environment (VR). In each of these 2 blocks, one condition assures the reliability of both vision and proprioception (VP), one blind (B) condition assures the reliability of just proprioception (P), and one condition assures the primary reliance on just vision (V). We label the conditions depending on which kind of environment and sensory information is available.

1. BR_P (Blind, Reality, only Proprioception is available, First-person view of body is unavailable)
2. BVR_P (Blind, Virtual Reality, only Proprioception is available, First-person view of body is unavailable)
3. R_VP (Reality, Vision and Proprioception are available, First-person view of body is available, room corners and clouds are visible)
4. R_V (Reality, Vision available, First-person view of body is unavailable, room corners are not visible, clouds are visible)
5. VR_VP (Virtual Reality, Vision and Proprioception available, First-person view of body is unavailable, room corners and clouds are visible)
6. VR_V (Virtual Reality, Vision available, First-person view of body unavailable, room corners are not visible, clouds are visible)

2.3. Results

All the analyses are conducted using the software R. The intra-class correlation index (ICC) has been calculated separately for each subject. The analysis estimates for every subjects an ICC>.99, with a 95% confidence interval being 1<ICC<1. This nearly perfect inter-coder agreement esteem derives from the small mean difference between the 2 coders' values, within the huge range of possible values (0/360). In fact, the mean difference between coder A and coder B, is minimal ($M_{A-B} < .2$).

2.3.1. TD children

The descriptive analyses of the dependent variable, the turn errors, are reported bellow.

TD children's turn errors, expressed in degrees, fall in a range from 0 to 117.5, have M = 20.3, median = 10.3 and SD = 24.9. The Shapiro-Wilk normality test reveals that the turn errors distribution cannot be considered normal (p < .01). The dependent variable has a skewed distribution with a positive asymmetry.

Age

We investigated whether the age influences participants' turn accuracy. We conducted the Spearman's rank correlation test. The analysis revealed a negative correlation between the age and the subjects' mean turn errors: the more the age the less the errors (rho = -.2). However, the effect is not significant (p = .45).

Conditions

We investigated how do TD children perform in different conditions. Turn errors density distributions in each condition is shown in figure 11.

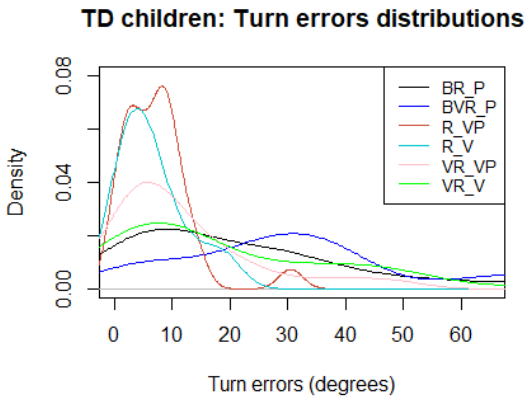

Figure 3: Turn errors density distributions of each condition, N = 26

Turn errors density distributions in R vs VR conditions, and in VP, V or P conditions (Fig. 12) are shown below.

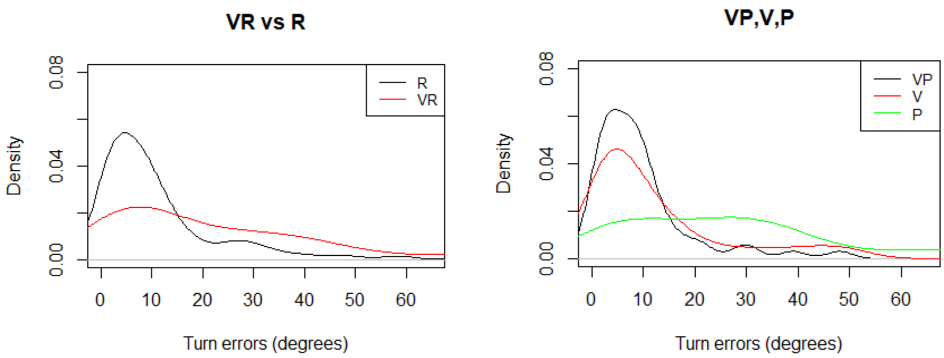

Figure 4: Turn errors density distributions of VR and R conditions (on the left), N = 78; and VR, V, P conditions (on the right), N = 52

Each condition mean and standard deviation of the turn errors is described above (Table 1). A boxplot graphically shows the turn errors in each condition (Fig. 13).

		M	*SD*
1.	*BR_P*	24.7	25.6
2.	*BVR_P*	37.2	28.5
3.	*R_VP*	7.3	6.2
4.	*R_V*	13.5	25
5.	*VR_VP*	19.1	24.9
6.	*VR_V*	20.1	20.1

Table 1: Conditions Mean and Standard Deviations

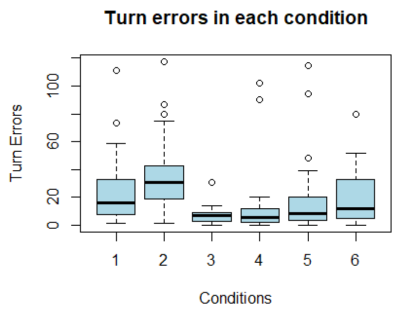

Figure 5: Boxplot of Turn errors distributions among conditions

2.3.2. Adults with ASD

Due to the high interindividual variability, and the small number of subjects in this group, we need to explore each individual's performance. Participants' mean errors in each condition is shown in table 2. There are some missing values because of the difficulty in engaging these participants. Only 3 of them performed all conditions.

Subject	***BR_P***	***BVR_P***	***R_VP***	***R_V***	***VR_VP***	***VR_V***
1	14,75	72,25	17,125	0,75	/	12
2	28	87,75	27,75	36,25	106,25	6,25
3	29,5	29,75	59	26,5	11,75	57,5
4	28	42,75	21	33,5	69,5	21,75
5	0,75	/	/	/	/	/
tot.	**20,2**	**58,125**	**31,21875**	**24,25**	**62,5**	**24,375**

Table 2: Adults with ASD: means

As for TD children group, we explored the turn errors density distributions in each condition (Fig. 15), in VR vs R conditions and VP, V, P conditions (Fig.16).

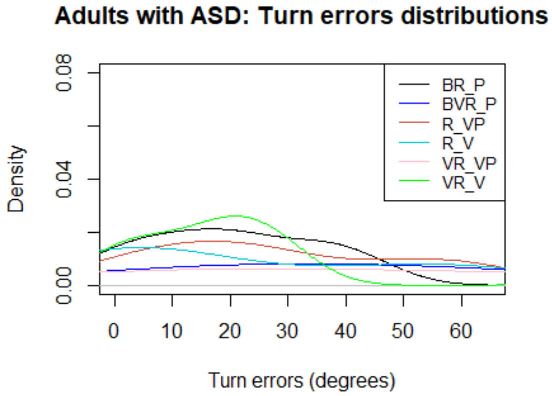

Figure 6: Turn errors density distributions of each condition

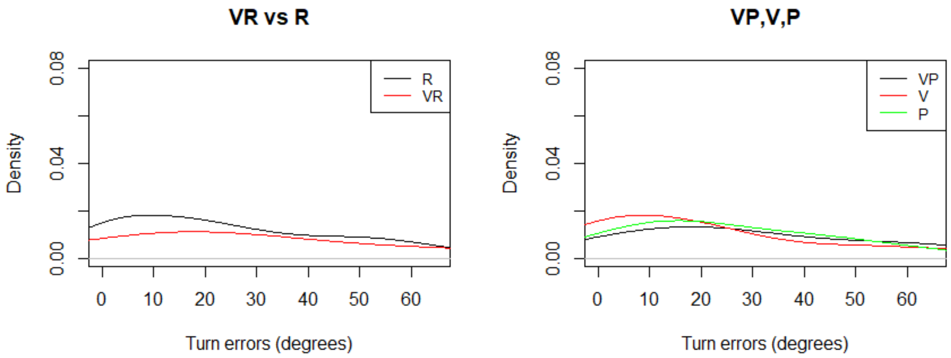

Figure 7: Turn errors density distributions of VR and R conditions (on the left); and VR, V, P conditions (on the right)

Discussion

In this preliminary phase of this research, we can examine the feasibility of our experimental design and procedure. We conducted the experiment on TD children and adults with ASD. Their turn accuracy in different conditions has been explored.

As expected, in TD children group, there seems to be a similar accuracy in real VP (the baseline) and V conditions, and less accuracy in P condition. This is in line with literature about children relying primarily on vision and being impaired when vision is not available (par. 1.4.3). Comparing real (R) and virtual (VR) conditions, we can notice a reduction of the accuracy in VR vs R conditions. This result was not expected based on literature and hypotheses. It makes us notice that HMD-delivered IVR per se reduces motor accuracy in TD children. TD children seem to be impaired by VR in all sensory conditions. Even when comparing blind R vs VR conditions, TD children's accuracy decreases while wearing the HMD. We can speculate that it is due to the HMD weight and head constriction, which interfere with motor accuracy. This is a new finding in IVR literature which has attributed HMD effects to FOV, visual stimuli features and input-output latency. However, we should compare TD children and TD adults' results to explore whether the HMD effects may be age-related.

We aimed to investigate whether the visual absence of the body reduces self-turn accuracy in VR. The first possible hypothesis was that IVR per se reduces self-turn accuracy, and this is not due to the absence of a VB. Supporting this hypothesis in TD children, we found a reduced self-turn accuracy in the VR_V condition compared to the R_V one (both without a visual body presence) and no difference between the two R conditions (R_VP and R_V), respectively with or without a visual body presence.

As expected, in the adults with ASD group there is a worse overall accuracy. However, it has been difficult to find a group-specific condition effect. When considering all participants with ASD together, and the turn errors density distributions, there seem to be no difference clearly due to virtual reality or sensory modalities. Reflecting on averages, it seems that adults with ASD show a better performance in unimodal (P, V) versus multimodal (VP) conditions, in both reality and Virtual Reality. The real "only proprioception" (BR_P) condition show the most accurate performance. This result would confirm our hypothesis and literature on people with ASD relying more on proprioception than vision, being not impaired in P vs VP conditions. However, the groups with ASD were also expected to be impaired in V vs VP conditions. This was not the case of our sample. The turn accuracy seems to be impaired by IVR in conditions including P. On the other hand, the accuracy is similar for R_V and VR_V conditions. These results could suggest that, when proprioception is reliable but altered by IVR, the accuracy is impaired. On the contrary, when proprioception is not reliable and only vision is available, IVR does not impair performance. We can speculate that adults with ASD can benefit from vision when proprioception is not available. Our long-term research goal, is to understand whether IVR could improve motor and sensory functioning in people with ASD. This could be achieved thanks to a reduction of the reliance on proprioceptive information and increased use of visual information. The adults with ASD in our sample seem to have a good motor accuracy in "only vision" environments. Further research will need to explore the sensory reasons underlying this result.

These results has to be interpreted as an indication for future research. In fact, our sample is limited and the testing phase is still in progress.

Future direction

We aimed to compare self-motion in reality and IVR environments. However, we did not include an IVR condition with a self-avatar. This could be interesting to better clarify the role of having or not the possibility to see our own body on motor accuracy and visuo-proprioceptive integration.

One intriguing perspective is the possibility to manipulate the IVR latency, the delay between the user's movement and the HMD reaction, to study the multisensory temporal binding window in IVR. There are evidences suggesting an iper-multisensory integration in people with ASD, who show an extended multisensory temporal binding window (Foss-Feig, Kwakye, Cascio, Burnette, Kadivar, Stone, & Wallace, 2010; Stevenson, Siemann, Schneider, Eberly, Woynaroski, Camarata, & Wallace, 2014). There seems to be an "enlargement in the time interval over which multisensory stimuli can influence one another" (Foss-Feig, et. al., pp.387). To our knowledge, no one in literature has explored visuo-proprioceptive temporal binding window. We have previously discussed in other sections of the present work, about how IVR seems to create a conflict between vision and proprioception. To our knowledge, there are no papers using HMDs which report the delay of their instruments between the user's movement and the technology reaction. We can speculate that this visuo-proprioceptive conflict decrease the overlap of these two sensory modalities. In this way, for people with ASD, both proprioception and vision could be more clearly perceived and processed. That could be the reason why perceptual trainings which manipulate the multisensory stimulation and disrupt multisensory temporal function can be effective interventions for ASD (*ibidem*).

Conclusion

The present study is a preliminary reflection on how IVR can be used to study multisensory functioning and development, in typically developing children and populations with ASD. We provided evidences suggesting that the individual sensory functioning can be detected in IVR as in real environments. Our results are consistent with other studies and show that TD children primarily rely on vision over proprioception to perform motor actions. Consistently with literature on TD adults, but surprisingly for our hypotheses, IVR per se seems to reduce motor accuracy also in TD children. However, it does not seem to be related to the sensory stimulation, but it could be probably due to the HMD weight. In conclusion, TD children's visuo-proprioceptive functioning in IVR and real environments seems to be consistent. In sum, this study summarized experimental and bibliographic evidences suggesting why could IVR be an useful tool for TD children and for people with ASD. Further research is needed, especially on groups with ASD, to establish a core knowledge on how IVR can interact with individual psychophysiological profile.

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