Effectiveness of an Immersive Virtual Environment (CAVE) for Teaching Pedestrian Crossing to Children with PDD-NOS

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***Abstract*—Children with Autism Spectrum Disorders (ASD) exhibit a range of developmental disabilities, with mild to severe effects in social interaction and communication. Children with PDD-NOS, Autism and co-existing conditions are facing enormous challenges in their lives, dealing with their difficulties in sensory perception, repetitive behaviors and interests. These challenges result in them being less independent or not independent at all. Part of becoming independent involves being able to function in real world settings, settings that are not controlled. Pedestrian crossings fall under this category: as children (and later as adults) they have to learn to cross roads safely. In this paper, we report on a study we carried out with 6 children with PDD-NOS over a period of four (4) days using a VR CAVE virtual environment to teach them how to safely cross at a pedestrian crossing. Results indicated that most children were able to achieve the desired goal of learning the task, which was verified in the end of the 4-day period by having them cross a real pedestrian crossing (albeit with their parent/educator discretely next to them for safety reasons).**

PDD-NOS; Autism; ASD; children; learning; CAVE; pedestrian crossing.

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is classified as a developmental disorder often appearing during the early development of a child's first three years of life. According to [1] and [2], autism is one of the fastest growing neurobiological conditions in the world. Associated with a host of various communication, behavior, and social difficulties, it not only presents itself in various degrees but it is grouped under an "umbrella" or referred to as a "spectrum disorder". There are three main types of spectrum disorders and they are classified as: Autistic Disorder (AD), Asperger's Syndrome, and Pervasive Development Disorder – Not Otherwise Specified (PDD-NOS) ([1],[4]). Although there is no known focus and single cause of autism, the prevalence of autism has vastly increased to 1 in 88 new births and 1 in 54 boys in the United States of America [3], a 23% rise from the figures of the 2009 study. All ASDs occur without prejudice across ethnic, racial, and socioeconomic groups [2].

After a thorough review of every child's recent medical history, we determined that the diagnostic test used by the physician was very important as well as the exact diagnosis given by the physician. From the assessment of this information we found that out of five (5) distinct types of Autism, we only had children to represent two (2) of these types, that is AD and PDD-NOS.

AD and PDD-NOS are distinct and important categories. According to the *Diagnostic and Statistical Manual of Mental Disorders, 4th edition* (DSM-IV), AD can be referenced by severe disorders in verbal and non-verbal behaviors, unusual behaviors, and it is commonly simply referred to as Autism. PDD-NOS can be referenced by children that do not often fit into any of the other categories. Characteristics can be difficult to assess because it can include a wide array of behaviors that span across multiple types of communication. Spatial perception problems, motor coordination problems, and a host of other characteristics not falling directly into other categories are grouped as PDD-NOS.

An immersive Virtual Reality (VR) CAVE application for learning safe pedestrian crossing had been developed by [5] and tested on 9-10 year old children without autism [6] with positive findings. Children responded positively about learning via an immersive virtual environment and could see the advantages of learning a topic like that in a safe but realistic environment, compared to learning about it in a traditional classroom setting.

Children with Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), Autism and co-existing conditions formed the next population on which we would try the application to observe its impact on learning. The characteristics for those two types of autism and their co-existing conditions lead to a target user group with very different needs and abilities compared to the previous one, therefore we had to adapt the application accordingly. As with the design of any assistive technology [7], the right way to identify the requirements it has to satisfy is through directly asking the intended users. A session was carried out with one child with PDD-NOS, in which we identified all the points/features that had to change or sometimes even disappear from the application. After tailoring it accordingly the application was tried out by 6 children over the course of 4 days. The children's conditions varied significantly. Two (2) children discontinued after the 3rd day, but the remaining four (4) managed to complete the 4-day "training phase" and were finally taken at a real pedestrian crossing to observe their behavior and see whether they could generalize the knowledge acquired from the virtual environment.

II. BACKGROUND

A. VR for teaching children with autism

The benefits of using virtual environments as remedial learning environments for children with autism are many. The features of virtual environments that make them suitable as learning tools for children with ASD are:

Controlled and safe learning environments: Virtual learning environments can provide safe environments, a less dangerous and more forgiving environment for developing skills associated with activities of daily living. In addition, mistakes are less catastrophic compared with the real world [8], [9].

Generalization: An important issue and problem of all therapeutic and teaching approaches for children with ASD is generalization. Virtual environments have the benefit of changing dynamically, create alternative scenarios or variations, and increase the complexity of scenario very easy [9], [10].

A primarily visual/auditory world: Virtual environments highlight visual and auditory responses rather than other senses such as touch. Such responses effectively involved in teaching abstract concepts to people with autism. Individuals with ASD indicate their thought patterns are primarily visual [8].

Individualized Treatment: Virtual environments deemed appropriate considering the ability to change dynamically and be customized based on each individual separately [8], [10] and customize the environment based on each person's abilities.

Preferred Computer Interactions: Children with ASD are characterized by proactive behavior, they prefer a predictable, structured and in this way 'safe' environment. They prefer to be in 'control' of the interaction and they respond well to structure, explicit, consistent expectations, and challenges provided by computers. Multiple studies have reported the advantages of computers in the treatment of ASD. Virtual environments are stable, familiar, predictable, and allow children to learn basic social interactions in a consistent and accepting way [8], [9], [10].

Embodied Interaction: Virtual environment devices (e.g. VR helmets, hand controls), might be unacceptable for many autistic children, but for others they might be appropriate. Approaches which support interactions involving the whole body seem highly promising; set ups where the child can move freely and is not constrained to sitting at a desk and is not required to wear special devices. The use of body and head trackers provides other advantages and possibilities. The movements and actions of an individual can be controlled in a virtual environment, allowing the system to adjust to a patient's actions. A large proportion of individuals with autism never learn to communicate, this calls for interactions in virtual scenes without verbal training from a teacher or other controllers.

Immersion: The sense of immersion refers to the feeling of being part of, or engaged in a virtual scene. Feeling like you are really inside the virtual environment. Studies like [11] and [12] have been carried out to demonstrate the benefits of the sense of immersion in VR systems, in terms of effective instruction and learning for people with autism.

Nevertheless, the overall scale of the research about VR for educational purposes generally and supporting social skills specifically, is undeniably limited. Because of the limited scale of research the results characterized as equivocal. One challenge is to design learning applications that provide the most effective combination of the features of VR technology (integrate VR with digital media) to support the required learning, to be educationally appropriate and useful. Parsons and Cobb [13] argue that the more realistic a virtual environment, the more generalization will be achieved, because the scene is more 'believable', and therefore skills and understanding are more likely to be transferred from the virtual to the real world.

Despite the significant body of existing research about VR for educational purposes for children with autism there are still missing references about the use of VR CAVE environments for this purpose and certainly about its benefits for low-functioning autistic children.

B. VR for teaching road crossing skills

In order for young children to become safe road users, they have to be exposed to traffic under supervision. Their own judgment will not be enough; they will need their supervisor's corrective feedback. Parents are generally the first to accompany children on trips, but unfortunately few of them really understand the limitations of young children, their skills at that age and the skills actually needed to be able to make safe road-crossing decisions. It is recommended that children be supervised until they reach the age of nine (9).

Children's road crossing skills and their behavior in traffic may be influenced by a variety of factors including demographics and individual differences, cognitive ability, as well as visual, attention and perceptual skills.

Much of literature suggests that young children are less competent in traffic than older children and adults because of poorly developed perceptual and attentional abilities, which consequently increases their risk as pedestrians [15], [16], [17].

Virtual Reality allows one to do more than merely mimic reality. If reality imitation was the only goal, then it may be simpler to manufacture physical props with which a participant could practice some procedure. For example, much surgical training is performed on animals and cadavers. What virtual reality adds is the ability to practice uncommon, expensive and dangerous tasks.

By practicing tasks in this computer-mediated system, other benefits are realized. Specifically, the simulation operator has more control over what scenarios can be presented to the trainee, and can change the scenario in response to performance. The other significant benefit is that performance can be recorded and analyzed.

The effectiveness of virtual reality has been tested in a pedestrian-safety training situations for children since 2002 [14] conducted a study with 7, 9 and 11-year old children, looking at their road-crossing judgments before an after training with a computer-simulated traffic environment. Trained children performed better, crossing more quickly, missing fewer opportunities to cross safely and generally demonstrating a better understanding of the factors considered when making crossing decisions. Schwebel et al [14] conducted an important study confirming the validity of human behavior in the virtual world matching the same person's behavior in the real world using an immersive, interactive virtual pedestrian environment.

III. EXPERIMENT

The experiment's objective was to expose children with PDD-NOS, Autism and co-existing conditions to an immersive learning application in a VR CAVE setting and observe their behavior, reactions, as well as measure its learning effectiveness with respect to safe pedestrian crossing. The latter would be done through recording the correct/incorrect steps followed in the crossing procedure, as well as successful and unsuccessful trials, aiming at observing an improvement over time. The children were asked to come to the VR CAVE facility four (4) times, over the course of four (4) days. Every time they would have four (4) trials each. Four sessions have been used by most similar studies as sufficient to observe success in learning. Their parent/ guardian/ educator always escorted children. Plenty of time was given to the children to explore the lab facilities and the research team members. The experiment would end with a final session on a different day, at a real pedestrian crossing (that resembled the one of the immersive application) to examine whether the children could generalize what they learnt.

The research team consisted of a special education/ autism specialist, a Human-Computer Interaction researcher with accessibility knowledge and a VR CAVE expert. The study received approval by the University Research Ethics Committee. Informed consent forms were obtained by the children's parent/guardian. Moreover, they were asked to fill out a demographic and background information form for their child reporting on its prior exposure to real life road situations. Parents/ guardians were informed that they could withdraw their child from the experiment anytime they felt so.

IV. PARTICIPANTS

Participant children for this experiment were a total of six (6) boys, aged 8-11years old. Two (2) of the children attended the First Grade (ages 8 and 9), one (1) student was in the Third Grade (age 9), two (2) were in Fourth Grade (age 10), and one (1) was in the Fifth Grade (age 11). All children have been diagnosed with ASD as a primary diagnosis. The children attending First, Third and Fifth Grades were diagnosed also with ADHD and the children in the Fourth Grade with Mental Retardation. Based on the District Committee of Special Education (Limassol, Cyprus) they all attend a special education unit in an inclusive setting school. The participation of children with ASD in this experiment was undertaken after the written approval of

Figure 1. The VR CAVE and its four projection screens, shown running the pedestrian crossing application.

their parents. According to the background questionnaire results, all children were able to carry out some basic daily tasks (such as dressing, preparing school bag, etc.) almost independently, were competent using tablets and other electronic devices, but had little exposure to pedestrian crossings, even with their guardians. Their guardians reported that their children probably didn't have a sense of danger. This is naturally difficult to estimate, given that these children are rarely left alone.

V. SETUP

The experiments took place in a four projection screens Virtual Reality system. Each screen has 2.44m x 1.83m projection area, three of them are used as wall screens (front, left and right) adapting rare projection ethnology and the fourth one as a floor screen with front projection, where users can slide on, wearing special footwear over their shoes. Four (4) computers connected over a network, each responsible for a screen, control the system.

The projections' resolution is 1600x1200 pixels, with a refresh rate of 120Hz, allowing active stereoscopy by projecting alternately renders for each eye.

Users are equipped with active stereo glasses in order to observe the 3D virtual environment. The user (the child in our case) wears a pair of stereo glasses with trackers attached on them, allowing 6-DOF (Degrees of Freedom) tracking of the head's movements. A 4 infrared camera Vicon system handles the tracking, providing all the needed information to render the projection images correctly, based on the user's point of view. An Xbox controller can be used for user interaction/navigation purposes.

By allowing the user to step in and adapting their point of view to the projections of the virtual world, VR CAVE serves a fully immersive experience.

VI. DESIGN

The initial immersive learning application that targeted children without autism (or perhaps with mild autism, although not tested on such) [5] was presented to a child with PDD-NOS, to identify the points that had to be tailored. Children had to learn the following procedure (6 steps) of safe crossing in the virtual environment: “Stop and wait on sidewalk”, “Press button and wait for green light”, “Look left and right when the light turns green, until all clear”, “Walk and continue looking”, “Use Cross Walk” and “Cross the road to reach the pavement”.

The original application was tested out with a low functioning autistic child, so as to determine the points that had to be modified, tailored to this user group’s needs. The Xbox controller was very distracting for the child and perhaps difficult to grasp with respect to its operation and therefore was removed from the application, transferring its interaction capabilities (moving forward and crossing) to the operator to control via keyboard. Our goal was to focus on children with PDD-NOS learning the procedure of crossing safely and not allow other cognitive tasks that might be irrelevant interfere with this. Furthermore, the “pushing the button” function was also transferred to the operator (via keyboard), to be triggered upon seeing the child extending its arm to push the button to cross.

Finally, we observed that it was difficult to restrict the child to slide on the bottom screen using the special footwear provided, which is a technical requirement to prevent the screen from being scratched. To overcome this issue we covered the floor screen with a white plastic film, allowing the child to walk on it freely with its own footwear. Fig. 1 depicts the VR CAVE itself, with the relevant pedestrian crossing application running.

VII. PROCEDURE

Children were given 3-D stereoscopic glasses to wear and had their special education teacher next to them at all times (Fig. 2). The teacher could hold them, or not, depending on whether it was necessary. Therefore physical help was provided if necessary and this was recorded in our data sheets per trial. Verbal help was also provided, when needed. No problems were observed with the acceptance of the 3-D glasses from the participating children.

Each child had four (4) trials, attempts to cross the pedestrian crossing in the VR CAVE, following the correct procedure, as explained to them. Observations were recorded throughout on data sheets, concerning all steps of the procedure and finally the overall success/ failure of the attempt. The sessions were also videotaped for reference and further study. Children repeated this over the course of four (4) days to ensure that they had reasonable time to learn this procedure.


Figure 2. A child participant with its educator in the VR CAVE


Figure 3. Snapshot of child having pressed the button and waiting for the green light (left). Snapshot of child crossing (right).

Subsequently, the children participants would be taken out at a real pedestrian crossing to see to what extent they could generalize what they learnt in the VR CAVE into the real world. This was carefully planned and organized to ensure safety above all. The parent/guardian, as well as the research team and another two assistants were involved in this, to minimize the probability of unforeseen incidents. These sessions were videotaped for reference and further study (see Fig. 3).

VIII. RESULTS

We will give the children fictional names, so as to refer to their performance individually. The two 10-year old boys with ASD and mental retardation withdrew from the study after the second day and therefore their data was not considered in the analysis. The remaining four boys had been diagnosed with ASD and ADHD. Jackson was the 8 year old; Oliver was the first 9-year old; Paul was the second 9-year old and finally Antony was the 11-year old.

As seen in Fig. 4 children made more mistakes in the procedure during the first days and trials, during which they also had verbal and sometimes physical help by the educator in the VR CAVE. Towards the fourth and last day, all four children had demonstrated progress, notably carrying out the procedure with no mistakes and no help. Most mistakes in the early sessions were observed at steps “Look left and right when the light turns green, until all clear” and “Use Crosswalk”. Antony’s performance was arguably better than the others, possibly because he was the eldest (he was 11).

On the fifth day, the four children were taken out at a

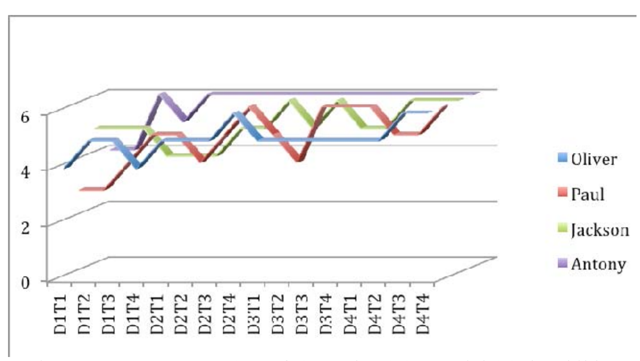

Figure 4. Correct Steps (out of 6) per day (D) per trial (T), by child

real pedestrian crossing to repeat the procedure they had learnt (Fig. 3). The research team had a strong (in number of persons involved to guarantee safety at the scene) but discrete presence (letting the child perform without obstructing). Four trials were conducted. Children appeared confident and just needed some time to adjust to the unfamiliar setting. After the first trial which was exploratory for most, they seemed to have made the generalizations needed and repeated what they had been learning at the VR CAVE. Antony once again, appeared to have mastered the procedure undoubtedly better than the others. The parents' feedback was very positive and encouraging. They described themselves as holding their children's hand (probably instinctively to protect them), and not their children holding theirs. They felt that their child could have not held their hand and performed the same. Another comment was that they felt the child pulling them forward to cross when they felt the time was right.

IX. CONCLUSION

We reported on a study we carried out with six children with PDD-NOS over a period of four (4) days using a VR CAVE virtual environment to teach them how to safely cross at a pedestrian crossing. Results indicated that four children were able to achieve the desired goal of learning the task in that simulated environment. The most challenging part, which was to see whether they could generalize and apply that knowledge in the real world followed, verifying that they could cross a real pedestrian crossing (albeit with their parent/educator discretely next to them for safety reasons). These findings are very encouraging for the population of low-functioning autistic children, for which research studies are sparse. The results were encouraging both for the participating children themselves because they felt the sense of achievement and for their parents because they felt proud of their children's performance, whereas initially they were skeptical. These results complement results of past studies that show the benefits of VR for children with ASD and constitute evidence for pursuing more studies among children with PDD-NOS.

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