Head-Mounted Display-Based Virtual Reality as a Tool to Teach Money Skills to Adolescents Diagnosed with Autism Spectrum Disorder *

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Abstract. In this paper, we present a study conducted to investigate the feasibility and effectiveness of Virtual Reality (VR) for teaching money skills to adolescents diagnosed with Autism Spectrum Disorder (ASD). Through a user-centered design, in collaboration with teachers at a special school for adolescents with mental disorders, a VR money skills training application was developed. A pre- and post-VR training evaluation was conducted on five students diagnosed with ASD using real coins and bills. The data triangulated with observations during the VR training sessions illustrates some potentials and benefits in using VR as a mean to teach money skills to adolescents diagnosed with ASD.

Keywords: Virtual Reality · Autism Spectrum Disorder · Everyday living skills training · Learning money skills

1 Introduction

Autism Spectrum Disorder (ASD) describes a spectrum of lifelong neurodevelopmental disorders that affect the social and everyday living skills of individuals diagnosed with it [1]. These deficits result in a dependence on support from parents or social agencies upon adulthood. A study conducted by Howling et al. measured the adult outcome of 68 individuals diagnosed with ASD with IQ above 50 [2]. The results show that only 3 out of the 68 individuals did not live with their parents and only 8 were independently employed. Another more recent study on 48 adults diagnosed with ASD and above the age of 24 showed similar results [3]. The study showed that 44 out of the 48 participants lived with families or in shared homes with caretakers. Furthermore, the study also showed that only one of the participants was independently employed while 48 % of the participants had never been engaged with work of any sort (part-time, voluntarily etc.).
Impairments in daily living skills (DLS) such as bathing, cooking, cleaning, and handling money can decrease individuals' chance for an independent adulthood.

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A study conducted by Farley et al.[4] on 41 adults diagnosed with ASD indicated that there is a direct correlation between daily living skills and independent adulthood. This confirms the importance of teaching DLS such as money management to children and adolescents diagnosed with ASD. Interventions designed to teach DLS might also help reduce the socioeconomic costs of individuals diagnosed with ASD [5]. This socioeconomic cost is estimated to be around 1.4 million dollars in the United States of America and 0.9 million pounds in the United Kingdom [6], consisting mainly of adult care services and loss of productivity. Furthermore, Leigh and Du estimate a significant rise in the annual medical- and non-medical economical cost of ASD in the United States of America from 268 billion dollars in 2015 to 461 billion dollars in [7]. The high prevalence of ASD (1 out of 50) [8] further emphasizes the agency for interventions to teach DLS to children and adolescents diagnosed with ASD.

Results from a literature review on interventions to teach social and everyday living skills to children and adolescents diagnosed with ASD illustrate that video modeling is a particularly effective method [10]. Video Modelling is a method that involves watching a video that illustrates the correct performance of the targeted DLS to be learned. Individuals diagnosed with ASD are better at processing and remembering visual information compared to verbal information [9], which can explain the high effectiveness of the video modeling interventions. Furthermore, Christy and Daneshvar argue that the reason why children diagnosed with ASD attend to video models more than real people is due to their social skills' deficits, making them uncomfortable around real people compared to video models [11]. In their review of intervention to increase the independence of individuals diagnosed with ASD [12], Hume et al. further underline the importance of DLS teaching interventions that do not require direct interaction with teachers.

Virtual Reality (VR) can be used to train daily living skills within relevant, interactive and immersive virtual environments. VR fulfills some of the above mentioned requirements for effective DLS training intervention such as mainly relying on visual information and not requiring direct interaction with the teachers. Furthermore, the advantages of computer-based learning interventions for individuals diagnosed with ASD over human-mediated interventions have been reported in several studies [12] [14]. One of the first studies investigating the potentials of VR to help children diagnosed with ASD was conducted by Strickland et al. in 1996 [15]. Two case studies were conducted in order to discover whether children diagnosed with ASD would accept and tolerate VR head-mounted displays and respond meaningfully to the virtual environment. The virtual environment consisted of a street setting including moving cars with disguisable colors. The child's task was to locate the cars in the scene and say out loud the color of each car. The results of the study showed that both participants accepted the VR head-mounted display while being able to fulfill the tasks within the virtual environment. Since then, there has been a number of studies investigating the effectiveness of VR to teach a variety of social and everyday living skills to

children and adolescents diagnosed with ASD. Adjorlu et al. conducted a study investigating the potentials of VR to teach social skills to children diagnosed with ASD [16]. A virtual classroom was developed with a number of interactive social scenarios with the purpose of teaching the children about sharing toys. The training sessions were facilitated by a teacher who controlled a virtual avatar using a microphone and keyboard. According to post-session interviews with the teachers, the children were able to have a productive discussion about sharing with the teachers after training with the VR application, showing their capability to relate to the social situations they experienced. In another study, Adjorlu et al. investigated the effectiveness of VR to teach shopping skills to children diagnosed with ASD [17]. The children could navigate in a virtual supermarket and pick up items listed on a virtual shopping list. Navigation was done via walking within the VIVE base station area. The user held a real shopping basket with a sensor attached to it in one hand and an HTC Vive controller in the other hand. The grabbing of items from the shelves was done using the HTC Vive controllers and they were then placed in the virtual shopping basket which was controlled with the real shopping basket. The intuitive interaction scheme was developed to increase the ecological validity of the VR training intervention. Ecological validity refers to the degree of similarity between an intervention and the real world 's counterpart. The virtual supermarket, its shelves, and the products on the shelves were designed to look like a real-world supermarket in order to increase the ability of transferring the skills trained in VR to the real supermarket. An in-between subject study was conducted, with the experiment group having seven VR training sessions while the control group received traditional lectures. Pre- and post measurements of all of the participants' shopping skills were done in a real supermarket. The experiment group performed worse in the pre-VR measurements compared to the control group while they performed better in the post-VR measurements. This study also illustrated the potentials of VR to train DLS, helping children diagnosed with ASD towards an independent adulthood. In this paper, we present a study investigating the potentials of VR and whether it can be used to teach money management skills to adolescents diagnosed with ASD. Purchasing skills and the ability to understand the concept of money and set personal budget is an essential step towards independent adulthood for children and adolescents diagnosed with ASD[18] [19] [20]. Through user-centered design via cooperation with teachers from a special school for adolescents with mental disabilities in Denmark, a VR application was designed and developed with the purpose of money skills training in adolescents diagnosed with ASD.

2 Method

2.1 Participants

The study was conducted at a special school for adolescents diagnosed with mental disorders at Rødovre municipality in Denmark. A total of nine students attend this school while five of them participated in this study. The five participants age ranged from 18 to 22 years old. All five participants were diagnosed

with ASD while one of them was also diagnosed with Aphasia. The participants IQ ranged from 40 to 61, and all five participants were male.

2.2 The VR Intervention

The VR money training intervention was developed through a user-centered design aimed at understanding the teachers' current context and needs when performing money skills training. Four teachers participated in an unstructured focus group interview. All four teachers worked at the special school for adolescents with mental disorders and all four had experience performing money skills training sessions with their students. During the focus group session, the teachers explained that they currently perform money skills training using role-playing sessions. Pictures of daily products are cut out from supermarket catalogs while the students receive fake money from the board game Monopoly. The roleplay training sessions involve the teachers showing the student one of the products and saying an imaginative price out loud that can be paid with the Monopoly money available to the students. Role-playing has been described as one of the important steps in practicing money skills in children with mental disorders, helping them to generalize their money skills to other contexts [21]. Cichak Grimm evaluated the effectiveness of monay skills training in a classroom setting by pretending that the teacher was the cashier and the students were going to buy something [22]. The results indicated that this role-playing combined with a variety of teacher instructions during the session was a successful method to teach money skills to children diagnosed with ASD. Therefore, the main part of the VR money training intervention will involve role-playing having to pay for a variety of products using virtual money that looks similar to real money. Furthermore, the teachers involved in the focus group session explained that they also perform simple exercises such as matching real coins and bills with different numbers to gain an understanding of the difference values of the coins and bills.

Based on the focus group, the VR intervention was divided into three levels:

1. Matching virtual coins and bills with the right image illustrating each specific coin or bill.
2. Matching virtual coins and bills with numbers illustrating the value of each specific coin and bill.
3. Practicing purchasing a variety of daily items by paying the right amount of money using the virtual coins and bills.

The VR money training intervention was developed using Unity 3D and C# scripting. The application was developed to run on the HTC Vive VR hardware. The virtual coins and bills were designed using textures from images of real danish money (see Figure 1) and included 50 Øre, 1 Dkk, 2 Dkk, 5 Dkk, 10 Dkk, 20 Dkk coins as well as 50 Dkk and 100 Dkk bills. All of the coins and bills

were placed on a table in the virtual environment. The coins and bills could be grabbed by the player using the grab button on the HTC Vive controller and released again by releasing the same button. A simple cartoonish low polygon park was designed as the surrounding environment for the VR money training application.

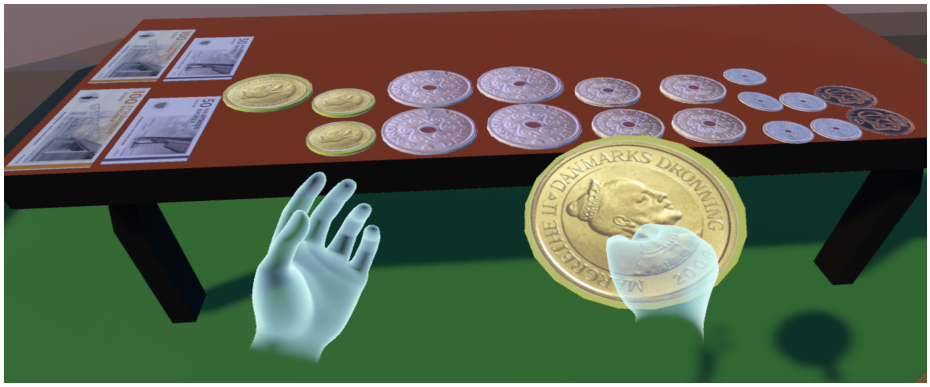

Fig. 1. The virtual money available to the student placed on a table on a table next to the users' starting position. The student can grab the coins and bills on the table using the grab button on the HTC Vive controller

For the first two levels, eight smaller tables were placed in the VR environment each representing a specific coin or bill either with a picture (level one) of that specific item or the number representing it (level two) (see Figure 2).

Fig. 2. Left: Level one within which the student must place the right coin or bill on the table with a image illustrating each coin and bill. Right: Level two. The student must place the right coin or bill on the table with the same number written on top of it. Green lights indicate correct answer. Red light indicate wrong answer.

The player's task in the two first levels was to grab one of the coins or bills and place it on the appropriate table. If the right coins or bill was placed on the correct table, a short positive earcon sound clip would play as a reward for the successful execution of the task. No negative earcon for failure was included in this iteration of the application. Feedback to wrong coin or bill placement was provided via a visual sign that would turn red in case of wrong answer and green in case of right answer. A clapping sound would play once all the coins and bills were placed on the appropriate table followed by the player surroundings changing to the next level.
For the final level, a bazaar stand was placed in the virtual environment. A variety of supermarket products would appear on the bazaar stand table, each having a different price. A cash register machine was also placed on the bazaar stand table, illustrating the price of the products via written text. A rigged 3D model of a salesman was placed behind the bazaar stand table (see Figure 3). He was programmed to ask out loud how much the product on the table would cost. A number of cues were programmed in the application. If the students did not successfully place the right amount of money on the table after 60 seconds, a voice cue would play telling the student the amount needed to be added or removed from the table in order to pay the correct amount of money for the product. Furthermore, if the student still had trouble placing the right amount of money on the table, another voice cue would be activated informing the player exactly which coins and bills should be placed on the table. The audio aids could also be activated by the student via the the trigger buttons on the HTC Vive controller. The teacher could also activate the audio guide by pressing the S and G buttons on the keyboard when she felt it was necessary. All the voice acting was done by one of the authors of the paper.

Fig. 3. The bazaar stand and its salesman. Each time the correct amount of money was placed on the bazaar stand, the 3D model would start dancing one out of the five animated dance moves

Once the correct amount of money was placed on the bazaar stand table, the 3D salesman would say "Thank you" out loud while performing one out of five animated dance moves to provide some positive feedback to the student (see Figure 3). A total of 25 products to pay for were included in the VR money training application.

2.3 Evaluation

The participants went through a total of five VR training sessions within a period of two weeks. Each VR training session lasted from 10 to 15 minutes. One moderator was present in the room, helping the students to start the developed VR DLS training application as well as taking observation notes during each training session. Screen video recording data was also gathered during each session. The moderator was well known by the students due to time spent working on the VR application in the school's computer lab. Pre- and post-VR training measurement of the participants' money skills was done by presenting the students with a total of 30 price cards, similar to the study conducted by Cihak & Grim [22]. These price cards were divided into three groups: ten price cards ranging from 0 to 50 Dkk, ten price cards ranging from 50 to 100 Dkk and ten price cards ranging from 100 to 150 Dkk. The student would have a collection of Danish bills and coins in front of him. The researcher would verbally state the price while presenting the written price card to the student. The researcher would then give the student 10 seconds to pay the right amount of coins and bills.

3 Results

The goal of this study was to investigate whether a VR money management training application can be designed to teach money management skills to adolescents diagnosed with ASD. Pre- and post measurements of the students' money skills were conducted and triangulated with observation data gathered during the training session to shed some light on the potentials of the VR application as a DLS training tool. +

3.1 Pre- and post measurements

The results of the pre- and post measurements of the students' money skills are reported in table 1. Student D and E failed to pay the right amount of coins and bills for any of the 30 prices during the pre-VR training evaluation with real money. During the post VR evaluation session, student E once again failed to pick out the right coins and bills during all 30 attempts while student D managed to pick out the right answer twice. Both of these students have an IQ below 50. Student C paid the right amount of money three times during the pre-VR evaluation while the right amount was paid eight times during the post VR evaluation session. Student C is diagnosed with both ASD and Aphasia with an

Table 1. Number of correct purchases made by each student before and after five VR money training sessions

Participant	before	After
Student A	19	30
Student B	9	30
Student C	3	8
Student D	0	2
Student E	0	0

IQ of 55. Student B answered correctly to nine of the prices presented to him in the pre-VR training evaluation while student A answered correctly to 19 of the prices. After five sessions of VR training, both of the students answered correctly to all 30 out of 30 prices. Both of these students have an IQ above 50 and below 61.

3.2 Observation results

Student A
During the VR money training sessions, student A seemed extremely comfortable, solving all of the tasks while he seemed to enjoy the process. He would pick up the coins and start juggling with them by throwing them up in the air and grabbing them again using the other controller/hand. He also enjoyed trying to throw the appropriate coins on the right table as if he was playing a game of basketball. He mentioned that he was expecting a feedback sound each time he put the wrong coin or bill on a table. He continued to effortlessly completing all the levels during the next four sessions while he seemed a bit bored with the training application on the 4th and 5th session, wanting to get it over without much juggling and throwing of the coins.

Student B
During his first attempt at completing level one in the VR training application, student B seemed to have problems distinguishing between 50 Øre, 5 Dkk, and 50 Dkk. After a number of trial and errors, he reacted to the positive feedback provided to him via the earcon and the visual green light on top of the table. After that, he finished most of the tasks without any issues. The only tasks that caused him some confusion were at level three where he was asked to pay 10.50 Dkk. He again first tried to place a 5 Dkk coins instead of the smaller 50 Øre coin. However, he eventually managed to place the right amount on the table. During the second training session, he once again had issues with the 50 Øre coin during level three. However, this was the last time he had an issue with any of the tasks, completing all of them effortlessly during sessions three, foure, and five.

Student C
Student C had issues distinguishing between 1 Dkk, 2 Dkk, and the 5 Dkk coins. Level one proved to be challenging again during the second VR training session. Level one was no longer an issue during session three, four, and five. Level two pose the same challenges as level one during the first, second and third training session. Level three where the user had to pay for a different variety of products was the most problematic level for student C. During first VR training session when asked to pay 3 Dkk for an item, he starts by placing a 10 Dkk coin on the table, or when he was asked to pay 10 Dkk he started by placing a 2 Dkk on the table, waiting for a respond from the seller. The audio guide was frequently activated, telling him exactly how much was needed to be added or subtracted from the table for him to complete each task. Some improvement in his level three performance was observed during the third VR training session where he managed to place the right amount of money when asked for simple prices such as 60 Dkk or 110 Dkk. He enjoyed throwing the coins and bills at the product, looking pleased each time he managed to hit the product from a distance. The coins and bills he threw were often the correct ones.

Student D
Student D struggled a bit with the control schemes of the VR training application in the beginning. However, after a short time, he got comfortable with the grabbing and placing of the coins and bills in the VR training application. The first two levels never seemed to cause him any trouble. Each time he picked up a coin or bill, he would say out loud the number on the coin or bill. He would then place it on the right table. On the contrary, level three seemed to be more challenging for him. While managing prices such as 3 Dkk, 10 Dkk, and 10.5 Dkk without any issues during his third VR training session, he consistently struggled a lot with prices such 65 Dkk, 25 Dkk or 15 Dkk throughout all of the training sessions. Whenever the 3D model of the virtual salesman danced (after the student had placed the right amount of money on the table) student D laughed out loud stating "He is dancing, he is dancing!".

Student E
Distinguishing between the 1 Dkk and the 2 Dkk coins was a problem for student E during level one in his first two VR training sessions. After a number of trial and errors, he managed to get used to the coins and place them on the correct tables. Level one and two was completed without any issues during his third, fourth, and fifth VR training session. He consistently struggled with level three during the first and second VR training sessions. The audio guide was activated for every single product, telling him on several occasions how much money needed to be added or removed from the table. During the third session, he started showing some improvement in level three, managing to place the right amount of money on the table for a number of prices without much effort. However, prices such as 65 Dkk, 85 Dkk, and 25 Dkk was still a big challenge, taking a long time and a number of trials before getting it right during all five sessions.

4 Discussion and Conclusion

The purpose of this explorative study was to examine whether VR can be used as a tool for adolescents diagnosed with ASD to train money skills. Pre- and post-VR training measurements of the participants' money skills was conducted, counting the number of correct purchases done by the students using real money. Four out of the five participants showed some improvement in their money skills after five training sessions with the VR application. Student E did not show any improvement, failing to complete any correct purchases during both the pre- and post VR evaluation sessions. Furthermore, students C and D illustrated very small improvements (from 3 to 8 and 0 to 2 correct purchases). However, noticeable improvements were observed in these three students performance during the VR training sessions. During the first two VR training sessions, none of these three students were capable of independently completing a single purchase with virtual money. During the third session and thereafter they all managed to occasionally place the right amount of money on the bazaar stand table without the need of trial and error or any of the audio guides. Future studies should, therefore, measure the students' performance during the VR training sessions, triangulating the data with the pre- and post-VR measurements using real money. This could shed some further light on whether the students lack the ability to generalize skills they trained and learned in the virtual environment to a real-world context. It has been suggested that individuals diagnosed with ASD have a reduced ability to generalize knowledge from one context to another [23] . According to behavioral analysts Stoke Bear, it is essential to include as many common stimuli in the training environment as there is in the environment within which the child diagnosed with ASD is suppose to perform the trained task [24]. The VR money training application developed for the purpose of this study included a number of common stimuli. As an example, the movement required to grab coins and bills and place them in front of a salesman is the same as in the real world thanks to the HTC Vive hardware.Another explanation for the inability to make a single correct purchase during the post-VR session with real money by student E might be him feeling uncomfortable performing in front of a real person compared to the 3D model of a salesman. Future iterations of the VR training application might include virtual environments such as supermarkets and shops in order to further close the gap between the training environment and the real world. Two of the students went through the post-VR evaluation with real money without making a single wrong purchase, showing that there is some potential in the VR money training application. Despite one of the students looking to be bored during his fourth and fifth VR training sessions due to the repetitive nature of the current version of the application, the students mostly showed that they enjoyed the experience, wanting to continue beyond the 15 minutes limit. Including gamification to some extent in the future iterations of the application might further increase the participants' motivation, which will be measured during future studies.

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