Vocational Rehabilitation of Individuals with Autism Spectrum Disorder with Virtual Reality

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In this article, a virtual reality system for vocational rehabilitation of individuals with disabilities (VR4VR) is presented. VR4VR uses immersive virtual environments to assess and train individuals with cognitive and physical disabilities. This article focuses on the system modules that were designed and developed for the Autism Spectrum Disorder (ASD) population. The system offers training on six vocational skills that were identified as transferrable to and useful in many common jobs. These six transferable skills are cleaning, loading the back of a truck, money management, shelving, environmental awareness, and social skills. This article presents the VR4VR system, the design considerations for the ASD population, and the findings with a cohort of nine neurotypical individuals (control group) and nine high-functioning individuals with ASD (experiment group) who used the system. Good design practices gathered throughout the study are also shared for future virtual reality applications targeting individuals with ASD. Research questions focused on the effectiveness of the virtual reality system on vocational training of high-functioning individuals with ASD and the effect of distracters on task performance of high-functioning individuals with ASD. Follow-up survey results indicated that for individuals with ASD, there was improvement in all of the trained skills. No negative effects of the distracters were observed on the score of individuals with ASD. The proposed VR4VR system was found by professional job trainers to provide effective vocational training for individuals with ASD. The system turned out to be promising in terms of providing an alternative practical training tool for individuals with ASD.

CCS Concepts: • **Social and professional topics** → **Assistive technologies**; **People with disabilities**; • **Computing methodologies** → **Virtual reality**

Additional Key Words and Phrases: Virtual reality, vocational rehabilitation, autism spectrum disorder

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1. INTRODUCTION

The U.S. Census Bureau estimates that there are 54.4 million Americans that have some form of disability [Brault 2012], 64% of which are classified as having severe disabilities. Severe disability can be defined as a physical or mental impairment that imposes a serious limitation on one or more functional capabilities in terms of an

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employment outcome [U.S. Bureau of Reclamation 2016]. According to the U.S. Bureau of Labor Statistics, the employment rate of has a ratio of 3:10 individuals with disabilities to individuals without disabilities [Bureau of Labor Statistics 2015]. However, more than 66% of the surveyed individuals with disabilities stated a desire to be employed [National et al. 2007]. The employment rate of individuals with Autism Spectrum Disorder (ASD) was reported to be lower than that for people with other forms of disabilities [Roux et al. 2015]. Accessibility to proper, safe job training is stated as a significant limiting factor in the employability of individuals with ASD [Autism Speaks 2014]. Previous work indicates that individuals with ASD who are trained repetitively with a customized program are more likely to attain and retain jobs that fit their unique skill sets and behaviors [Autism Speaks 2013]. Employment is an important factor in increasing quality of life and providing a sense of achievement and independence to individuals with disabilities [Schur 2002; Yasuda et al. 2002]. It was reported that a majority of individuals with ASD did not show traditional markers for adult independence [Shattuck et al. 2012]. This article presents results in favor of using immersive virtual reality as an alternative training tool to address the job training gap for individuals with ASD, especially when performed in supervision of professional job trainers and coupled with follow-up conventional on-site job training.

Virtual reality (VR) is defined as "a model of reality with which a human can interact, getting information from the model by ordinary human senses such as sight, sound, and touch and/or controlling the model using ordinary human actions such as position" [Hale and Stanney 2014]. Immersive VR is a type of VR in which the users are completely surrounded by the virtual environment as if they stepped inside the virtual world. This is usually achieved by means of a Head Mounted Display or cave automatic virtual environment (CAVE)-like projections on surrounding big displays. As VR has become more prevalent and affordable, VR applications for training and rehabilitation of individuals with ASD have been increasing in recent years. Virtual reality offers several benefits that cater to the characteristics of individuals with ASD, such as (1) increased safety as training experiences are virtual and take place in controlled physical environments; (2) customization of training through creation of personalized scenarios and real-time individual-specific adjustments, such as increasing difficulty level or limiting distracting elements of a scenario; (3) repetitive training opportunities without any fatigue in virtual characters; (4) real-time smart prompts in the form of animations, pictographs, and written and verbal cues that are contextualized to the scenario at hand; (5) recreation of virtual scenarios that are rare to observe in real life such as a thunderstorm or a child having a tantrum; (6) automated session recording, data collection, and assessment and reporting for reflection; and (7) reduced transportation to training sites and corresponding transportation costs [Strickland 1997; Dautenhahn 2000; Parsons and Mitchell 2002; Goldsmith and LeBlanc 2004; Wang and Anagnostou 2014].

The proposed virtual reality system for vocational rehabilitation of individuals with disabilities (VR4VR) originally aims to improve job training in safe and customizable virtual environments for three disability groups: Autism Spectrum Disorder, Traumatic Brain Injury, and Severe Mobility Impairment. However, this study focuses on the aspects of the system that are related to individuals with ASD only. In the design, in house testing and iteration phases of VR4VR, significant input was taken from five professional job trainers who are Florida state–approved vocational counsellor experts who train individuals with Autism daily for a wide range of jobs and have significant experience and insight into training this population. The job trainers had certifications of Supported Employment, Vocational Evaluations, and the Health Insurance Portability and Accountability Act (HIPAA). An earlier version of our system can be found in Bozgeyikli et al. [2015]. After several testing sessions and discussions with the job trainers, the system was iterated to cater to high-functioning individuals with ASD.

A user study was performed with nine neurotypical users and nine high-functioning individuals with ASD. The aim of the user study was to explore the effectiveness of the proposed VR4VR system in training individuals with ASD on six transferrable job skills.

This article is an expanded version of the short article that was presented at the IEEE Virtual Reality 2016 conference's Workshop on Everyday Virtual Reality [Bozgeyikli et al. 2016]. This article includes the following new content: (1) expanded related work, (2) detailed description of the skills of the iterated VR4VR system, (3) user study results for nine neurotypical individuals and nine high-functioning individuals with ASD, (4) statistical analyses of the experimental results, (5) expanded lessons learned, and (6) expanded discussion in light of the user study results.

Our main contributions in this article are as follows: (1) presentation and design considerations of a comprehensive VR system for vocational rehabilitation of individuals with ASD, (2) user study results of nine neurotypical individuals and nine high-functioning individuals with ASD, and (3) good design principles for future VR systems targeting individuals with ASD.

2. RELATED WORK

Applications that use virtual reality for training individuals with ASD on several topics have been increasing lately. Early studies focused on exploring acceptance of VR by individuals with ASD and confirmed that VR was accepted by this population [Strickland 1997; Goldsmith and LeBlanc 2004]. Then, some studies concentrated on whether VR would provide effective training with successful transfer rates of the learned skills from virtual worlds to real life. Many studies concurred, reporting results that indicated successful generalization of the learned skills and successful transfer to real life [Strickland 1996; Marcus et al. 1996; Leonard et al. 2002; Mitchell et al. 2002; Parsons and Mitchell 2002; Crumrine 2006; Self 2007; Scudder et al. 2007; Herrera et al. 2008; Parsons and Cobb 2011; Smith et al. 2015].

Since intervention from the early ages is considered more beneficial, many studies focused on the use of virtual reality for rehabilitation of children with ASD. Lorenzo et al. studied an immersive VR environment for supporting social skills and executive decision making of children with ASD [Lorenzo et al. 2013]. Self et al. utilized a VR environment to teach fire and tornado safety skills to children with ASD [Self et al. 2007]. Josman et al. studied the effectiveness of VR in teaching safe street crossing skills to children and adolescents with ASD [Josman et al. 2008]. Maskey et al. focused on using VR along with cognitive behavior therapy to reduce some phobia and fears, such as crowded buses and pigeons, in young people with ASD [Maskey et al. 2014]. Cheng et al. used immersive virtual environments to enhance social skills of children with ASD [Cheng et al. 2015].

There also have been some studies that examined the effective use of VR in training adults with ASD. Wade et al. utilized an advanced VR driving environment to train individuals with ASD on driving skills [Wade et al. 2016]. Many studies focused on improving social skills of individuals with ASD, which is a common deficiency related to the ASD diagnosis. Smith et al. used an immersive VR system for training individuals with ASD on job interview skills [Smith et al. 2015]. Lahiri et al. developed a VR system for social communication skills training of individuals with ASD [Lahiri et al. 2011]. Miller and Bugnariu looked into the effects of level of immersion on the efficacy of VR on teaching social skills [Miller and Bugnariu 2016].

All of these previous works provided valuable insight and different perspectives on how to utilize VR for effective training of individuals with ASD such as using scores and feedback mechanisms, rewarding affirmative words, visually enhanced presentations such as simple picture cues and videos, structured schedules with routines, repetition, gradually increased difficulty, and simple controls and simple verbal cues. These components were observed to engage the users and to provide a comfortable learning and training environment. Results of these studies indicated that VR was a suitable and effective medium for individuals with ASD to learn and train. Many studies also indicated findings on the successful transfer of the learned skills afterwards.

Previous studies did not focus on any vocational skills other than the social skills. Our system mainly differs from the mentioned previous studies in utilizing several vocational skills in different immersive virtual environments. This way, we were able to explore training individuals with ASD on six different vocational skills using VR. We also evaluated the effects of virtual distracters on the performance of individuals with ASD. Each skill module had varying difficulty levels in itself and the system had different components that provided different experiences in different modules. This enabled us to reflect on several aspects of VR, related to vocational training of individuals with ASD. This study also aims to contribute to good design practices for future VR systems, based on the observations made during the user study sessions, comments from the participants and the job trainers, and the user study results.

3. VR4VR SYSTEM

Our VR4VR system aims at training individuals with ASD on transferrable vocational skills in immersive virtual environments. The system is composed of the following hardware components: a VR2200 Head Mounted Display (HMD), an optical motion tracking system with 12 OptiTrack Flex:V100 cameras that track an area of 8ft by 8ft, a large 180° curved curtain screen, touch screen controls, tangible objects equipped with optical markers that can be tracked by the system in real time, and a remote control panel for the job trainers. For the selection of the HMD, professional job trainers recommended using an HMD that allowed for some open space in order not to break the whole connection of the participants with the real world, since it would have caused discomfort in individuals with ASD. Following their recommendation, the VR2200 HMD was selected, which had small holes on the eyecups and could be flipped over when not in use. The software was developed using the Unity game engine. To run the developed software, a desktop computer with the following specifications is used: an AMD FX-8150 8-Core Processor, an AMD FirePro W600 Graphics Card, and 16GB Memory.

There are several virtual environments in which the skill modules take place such as warehouse, grocery store, outdoor parking lot, office space, and street. Each skill module has its own tutorial level at the beginning that explains to the user how to perform the relevant task. Throughout the skill modules, several prompts are used that remind the users how to perform the requested task. There are several distracters that are automatically applied in the third levels of the training modules such as virtual coworkers, lightning, announcements, and fireworks. Additional distracters can also be applied manually by the job trainers.

3.1. Skill Modules

Our VR4VR system was designed to offer vocational training in the form of transferrable skills that were selected based on their prevalence in the employment of individuals with ASD based on the reports [O*NET 2016, JAN 2016, Bureau of Labor Statistics] and inputs from the professional job trainers. The reason behind the selection of transferrable skills was to enable the participants to apply the skills they had trained on to various possible jobs, hence increasing their chances of employment. The vocational skill modules consist of cleaning, loading the back of a truck, money management, shelving, environmental awareness, and social skills.

Each skill module is structured to have three subtasks of increasing difficulty, each having their own three levels. The first level consists of a tutorial and one instance of the relevant task. After the user completes the tutorial level successfully, the second level is presented in which the user performs the task that was learned in the tutorial

Fig. 1. Practicing cleaning skills.

level. In this level, there are no distracters to help the user reinforce the learned task without any disturbing factors. As the user completes the second level successfully, the third level with the distracters is presented, in which the user needs to perform the learned task in the presence of several VR distracters.

Three of the six skill modules were designed to be performed with the HMD (cleaning, shelving, and environmental awareness) and the remaining three skill modules were designed to be performed with the 180° curved screen (loading the back of a truck, money management, and social skills). In selection of these displays, literature and inputs from the professional job trainers was taken into consideration. For the skills in which movements of the user did not contribute to the performed task, a curtain screen was employed, since it was mentioned that some individuals with ASD may not like wearing additional objects on their bodies [Guidelines for Educating Students with Autism Spectrum Disorders 2010].

3.1.1. Cleaning Module. The cleaning module aims to train individuals with ASD on vacuum cleaning, mopping, and litter collection subtasks (Figure 1). The vacuum-cleaning and the mopping subtasks take place in a virtual warehouse and the litter collection subtask takes place in a virtual grocery store. The user wears an HMD and hand and foot bands with optical markers so their movements are tracked by the system in real time. The main objective of the vacuum-cleaning subtask is to vacuum clean the piles of dry dirt that are scattered around the warehouse. In the mopping subtask, the user needs to mop all of the puddles. In the vacuum-cleaning and the mopping subtasks, the user uses a tangible broomstick that is tracked by the system in real time. In the litter collection subtask, the user needs to collect all of the litter and throw it into virtual trash bins. To grasp litter, the user needs to bend and touch the virtual litter with his or her hands, which makes the virtual litter stick to his or her hand. After that, when the user walks near a virtual trash bin and extends his or her hand, the litter automatically falls down.

3.1.2. Shelving Module. The shelving module was designed to train users on warehouse organization, order, and delivery fulfillment skills. This module takes place in a virtual warehouse environment (Figure 2). The user fulfills tasks using tangible boxes that are equipped with markers. Although the physical boxes are identical in appearance, different virtual textures are projected onto them inside the virtual world.

3.1.3. Environmental Awareness Module. The environmental awareness module aims at training users on being aware of their environmental conditions and taking actions accordingly, such as collecting shopping carts in a parking lot while paying attention to moving cars and people (Figure 3). In the first and the second subtasks, user needs to

Fig. 2. Practicing shelving skills.

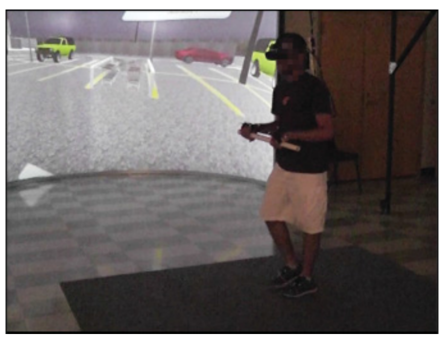

Fig. 3. Practicing environmental awareness skills.

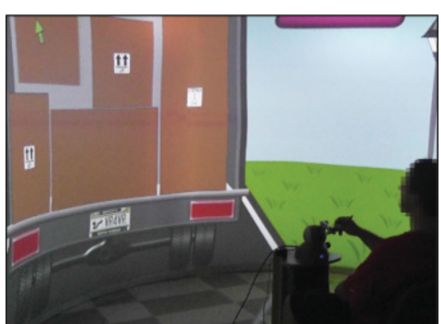

Fig. 4. Practicing the loading-the-back-of-a-truck skills.

go to the destination points. In the third subtask, user needs to collect virtual shopping carts in the parking lot. In this subtask, a physical pipe is given to the user to be held at all times, resembling holding a real shopping cart. The reason behind this tangible prop was to train the users on navigating carefully while their hands were busy and their attention could be divided. This prop was integrated into the system following the recommendation of the job trainers. The users performed marching in place gesture in order to walk in the virtual world.

3.1.4. Loading-the-Back-of-a-Truck Module. In the loading-the-back-of-a-truck module, users were trained on fitting boxes of several dimensions into a restricted area—the back of a truck (Figure 4). All subtasks take place in an outside street virtual environment. Virtual labels on the boxes in the second and the third subtasks indicate

Fig. 5. Practicing money management skills.

Fig. 6. Practicing social skills.

various properties such as *heavy*, *up direction arrow*, and *fragile*. These boxes should be placed based on the instructions related to their labels. The users controlled a force feedback haptic device in order to move and rotate the boxes.

3.1.5. Money Management Module. The money management module aims at training users on cash register related skills (Figure 5). The module takes place in the cash register area of a virtual grocery store. The user interacts with a tablet computer resembling the cash register. The user interface inside the tablet computer was designed in accordance with the real cash register screens in order to train the users properly. Onto the curtain, a virtual grocery store is projected with virtual customers and cashiers.

3.1.6. Social Skills Module. The social skills module aims at training individuals with ASD on conversational abilities (Figure 6). In these subtasks, virtual people ask some questions to the user and request them to answer. The questions were designed to be open ended so they resemble maintaining a conversation, such as *"If you see a lost child in the store, what would you do?"* The first subtask takes place in a virtual office environment, the second subtask takes place in a virtual grocery store, and the third subtask takes place in a virtual warehouse environment. The questions were dubbed with different attitudes such as friendly, over friendly, rushed, bossy, anxious, and indistinctive. This enables the job trainers to observe the users' reactions to different attitudes and train them accordingly. The job trainers use a tablet computer interface to control the questions to be asked. The users verbally answer the questions as they would do in real life and the job trainers trigger new questions based on the users' answers. The job trainers can also ask their custom questions during the training

Table I. Skill Modules with Their Relevant Properties

Skill Module	Subtasks	Distracters	Reinforced Subskills
Cleaning	•Vacuum cleaning •Mopping •Litter collection	•Loud vacuuming sound •Falling object sound •Intercom announcements •Lightning, rain and thunder sound	•Attention to detail •Observation •Inspection
Shelving	•Aligning boxes •Fulfilling orders and deliveries with graphically labeled boxes •Fulfilling orders and deliveries with item coded boxes	•A virtual forklift passing by •Coworkers walking while chatting •Change in the light temperature •Falling object sound •Lightning and rain sound	•Organization •Following the instructions •Attention to detail
Environmental Awareness	•Navigating while avoiding stationary objects and puddles •Navigating while avoiding moving people, stationary objects and puddles •Collecting virtual carts while avoiding moving cars, moving people, stationary objects and puddles	•Fire truck passing by •Christmas bells sound •Loud helicopter passing by •Colorful fireworks in the sky •Rain in the form of visual and sound	•Alertness •Observation •Navigation
Loading the Back of a Truck	•Loading identical boxes •Loading labeled boxes •Loading labeled boxes within a short timeframe	•Barking dog •Plane passing by •Day time to night time transition •Truck alarm with sound and lights •Heavy traffic sound	•Organization •Alignment •Quantitative reasoning
Money Management	•Recognizing coins and bills •Counting money •Providing the correct amount of change	•Store alarm with sound and lights •Ringing office phone •Running child •Loud upbeat music •Angry complaining customer •Intercom announcement •Infant crying loudly	•Arithmetic •Attention to detail •Organization
Social Skills	•Basic questions on personal information •Intermediate questions on the previous experience and observation •Advanced questions on vocational reasoning and preferences	•Butterfly flying •Office phone ringing sound •Ceiling fan operating •Laughing sound •Coughing sound •Whistling sound	•Attention to what others are saying •Maintaining conversation •Observation and reasoning

sessions. These questions are recorded by the system and later added to the existing set of questions.

A table showing all six skill modules with their corresponding subtasks, distracters, and reinforced subskills is presented in Table I. Each subtask has three levels of tutorial, including training without distracters and training with distracters.

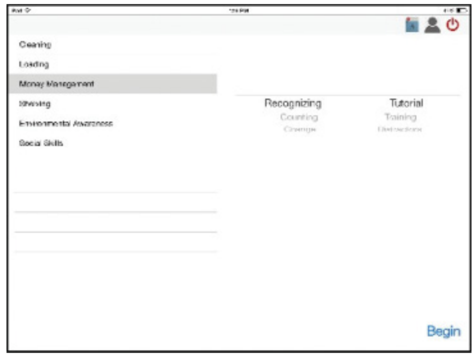

Fig. 7. Job trainer's controlling interface.

Fig. 8. Examples of the assistive prompts used in the VR4VR system.

3.2. Job Trainer's Interface

Although VR4VR aims at training individuals with ASD with as much automation as possible, we are aware that individuals with ASD may have different characteristics [Hendricks 2010], as the word *spectrum* implies, and may not benefit efficiently from a single solution. Therefore, our main goal is not to replace job training with a VR system but rather to assist the job trainers with a VR system that enables them to run many scenarios with different difficulty levels in various virtual environments. With this motivation, we provide the professional job trainers with a remote control interface on which they can control various parameters of the system, such as starting and stopping the modules/subtasks/levels; taking notes that are saved into the database; triggering distracters; and keeping track of the elapsed time, remaining instances, and scores (Figure 7). The remote control interface was implemented on a separate tablet computer. Each job trainer had a private and secure account, which stored information about their trainees such as the date/time of each training session, skills that were trained on, scores, and performance reports.

3.3. Assistive Prompts

Our VR4VR system utilizes various assistive prompts to help the users to remember how to perform the vocational tasks (Figure 8). In each level, if the user cannot perform the relevant task within a minute, a prompt is presented in the form of verbal instructions, pictographs, and animations. These assistive prompts were designed to be brief and simple, following the recommendation of the job trainers and the literature [Guidelines for Educating Students with Autism Spectrum Disorders 2010].

Fig. 9. Tutorial level of the money management module.

Fig. 10. Fireworks distracter in the environmental awareness module.

3.4. Tutorials

Motion tracking imposes some limitations on the actions that can be performed, calling for gestures or other forms of input. Hence, virtual training modules require the users to perform some tasks by following some directions. In our system, to explain to the users how to perform these tasks, tutorial levels were presented in the beginning of each subtask. These tutorials were designed such that a virtual instructor would stand across from the user, facing him or her, and then tell the user what needed to be done and then show the user how to do that by performing the task (Figure 9). The reason for the virtual instructor showing the user how to perform the task is because of the job trainers' guidance as well as the previous studies indicating that individuals with ASD learn best by demonstration [Hagner and Cooney 2005; Notbohm 2005].

3.5. Distracters

Individuals with ASD may negatively respond in various ways to out-of-the-routine common events, such as chatting co-workers and scraping noises, which may cause a shift in their attention [Hendricks 2010]. These responses can be considered a contributing factor to their low employment rate, as employers may not know how to respond to these reactions [Hagner and Cooney 2005]. In our VR4VR, we utilized a wide range of virtual distracters in the form of audio, visuals, and animations that are difficult to replicate instantaneously in real life such as thunderstorms and fireworks (Figure 10). These distracters can be triggered both by the system automatically and by the job trainers manually in real time. This way, the job trainers can assess the users' reactions to certain distracters and focus on some to practice overcoming them or omit some if they think that the user will not be able to overcome these distractions. The job trainers can later make sure that the user will be directed to jobs that minimize the risk of being exposed to these types of distracters.

3.6. Scoring and Assessment

To evaluate trainee performance based on the system parameters, a custom scoring algorithm was implemented. For the scoring algorithm, completion time, number of prompts, and number of incorrect actions were taken into consideration. The score has a possible maximum value of 100 for each subtask. Possible deductions are as follows: −30 points for each error made and −20 points for each prompt presented. The score has a possible minimum of 0 points. If the user cannot complete a level within 5 minutes, then this and the following levels of the relevant subtask is considered as failed with a score of 0. The system will not proceed to the following levels of this subtask unless the job trainer manually starts it. Errors constitute placing the boxes of orders and deliveries at the wrong location or leaving the boxes in the wrong alignment in the shelving module, colliding with the stationary objects/moving people/moving cars and stepping on puddles in the environmental awareness module, breaking a fragile box by dropping it from a large height in the loading the back of a truck module, selecting the wrong coins or bills in the money management module, and giving an unrelated answer to the asked question in the social skills module. As the user completes a level successfully or fails to complete it within 5 minutes, the score is immediately presented to them to provide a means of tracking their own performance, following the literature and the recommendation of the job trainers. The score is accompanied by a visual stating *"level accomplished"* or *"level failed,"* according to the user's performance, to help him or her comprehend his or her performance.

4. USER STUDY DESIGN

4.1. Demographics

Nine neurotypical individuals without any disabilities (control group) and nine high-functioning individuals with ASD (experiment group) participated in the user study. Both population groups were college aged ($\mu = 29.00$, $\sigma = 9.02$ for neurotypical and $\mu = 25.44$, $\sigma = 6.25$ for ASD). All individuals with ASD were high functioning and job seekers. None of the participants (neurotypical or ASD) had a prior experience of training on these six transferrable skills, using virtual reality or wearing a Head Mounted Display. Individuals with ASD were diagnosed by medical professionals with high-functioning Autism beforehand, and all had IQ scores higher than 70. Neurotypical participants attended the testing alone, whereas individuals with ASD were accompanied by a professional job trainer. In total, five qualified job trainers accompanied the participants with ASD in the study.

4.2. Hypotheses

Hypotheses were focused on the effective training provided by the proposed system and effects of distracters on performance: **(H1)** There will be improvement in individuals with ASD who trained with the VR4VR system in terms of the six vocational skills. **(H2)** Distracters will affect score of individuals with ASD in VR4VR negatively.

4.3. Procedure

The testing procedure was as follows: The users arrived in the laboratory, and they read and signed the consent form. After that, the research staff walked the participant through the wearable equipment and the motion tracking system and helped them to wear the HMD and hand/feet markers, if the first module included them. Then, the user was presented with the tutorial level of the first skill module and went through all of the subtasks in each skill module. Completion of the skill modules was followed by breaks and filling out surveys. Neurotypical individuals completed the testing in one session of approximately 4h. Individuals with ASD completed the testing in two

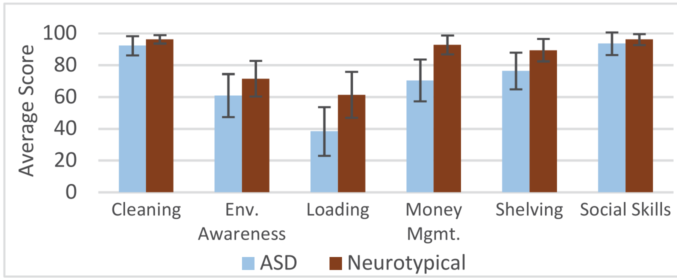

Fig. 11. Average level scores for the two user groups.

separate sessions of 2h that were scheduled on separate days since the job trainers stated that this would be better for them instead of a whole session. The order of the modules was selected randomly. All participants went through each module once.

4.4. Instruments

During the testing, the system collected data in the background, such as level score, time logs of successful and wrong actions, time logs and types of distracters, time logs and number of prompts, and session durations. The participants and the job trainers were requested to fill out surveys after the completion of each skill module. These surveys were designed as modified versions of Loewenthal's core elements of the gaming experience questionnaire [Loewenthal 2001] and consisted of questions assessing different aspects of the system such as enjoyment, dizziness, nauseousness, tiredness, and immersion. All sessions were video recorded via a real-life camera and a virtual camera inside the simulation.

5. EXPERIMENTAL RESULTS

In this section, results of the user study are presented. Although our main focus is individuals with ASD, data of the neurotypical individuals were also shared as the control group

5.1. Automated Data Collection

Level Scores

Average level scores for neurotypical individuals and individuals with ASD are presented in Figure 11. Error bars in all of the charts are standard error of the mean values. The chart presents the average of scores from level 2 and level 3 of all subtasks for every skill module. Tutorial level scores were discarded for both populations. As one-way analysis of variance (ANOVA) with repeated measures was performed with $\alpha = 0.05$ for the level scores of individuals with ASD, and the results were as follows: $F(5, 3) = 6.988$, $p = 0.01$, meaning that there was significant difference between the level scores of different skills. As two sample t-tests were performed, the results presented in Table II were obtained.

Distracters

During the testing sessions, distracters were triggered both automatically and by the job trainers. The job trainers tried to trigger similar numbers of distracters for each participant. However, the number of distracters applied for each participant may have varied based on how quickly they completed their training session and the difference in the manually triggered number of distracters by the job trainers. On average, six distracters were applied per level. Average scores for individuals with ASD in the absence and presence of distracters are presented in Figure 12. As t-tests were performed for

Table II. *T*-test Results for the Level Scores of the Individuals with ASD for Different Skill Modules.

Skill Pair		Mean Difference	Std. Error	*p*
Cleaning	Env. Awareness	32.933*	6.073	0.006
Cleaning	Loading	57.000*	19.468	0.043
Cleaning	Money Mgmt.	30.667*	10.822	0.047
Cleaning	Shelving	15.667*	3.100	0.007
Shelving	Env. Awareness	17.267*	3.244	0.006
Social	Env. Awareness	30.600*	8.102	0.019
Social	Loading	54.667*	16.154	0.028

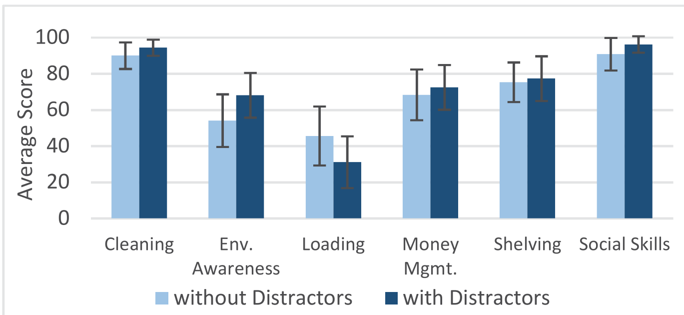

Fig. 12. Average scores for individuals with ASD for the without distracters and with distracters cases.

Table III. *T*-test Results for the Level Scores of the Individuals with ASD for without Distracters and with Distracters Cases

Skill	t-stat	p
Cleaning	−0.7332	0.4685
Environmental Awareness	−0.9909	0.3294
Loading the Back of a Truck	0.9428	0.3524
Money Management	−0.3639	0.7176
Shelving	−0.1561	0.8771
Social Skills	−0.8752	0.3860

the data of individuals with ASD using an α value of 0.05, no statistically significant difference was detected. Although it is not ideal to apply *t*-tests to this data, since the job coaches manually triggered distracters as well, we assumed this as a relaxation and still applied *t*-tests to obtain a general idea. Results of these *t*-tests are presented in Table III.

5.2. Survey Quantitative Data

5.2.1. Participant Data.

Tiredness

As the question *"How tired were you after completing these skill tasks?"* was asked to the participants with choices based on a five-point Likert scale ranging from "1: Not tired at all" to "5: Very tired," the results were as presented in Figure 13. Level of tiredness is important in regards of task design, since the system needs not to make the participants more tired than necessary for the training, for a good experience. This would enable training repetitively. As one-way ANOVA with repeated measures was performed with $\alpha = 0.05$ for the tiredness scores of individuals with ASD, the results were as follows: $F(5, 3) = 1.361$, $p = 0.311$, meaning that there was no significant difference between the tiredness scores of different skills.

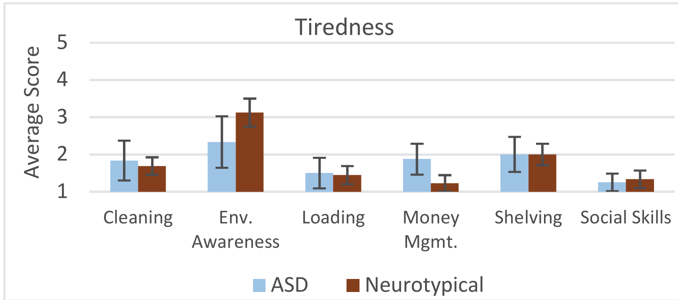

Fig. 13. Average tiredness scores for the two user groups.

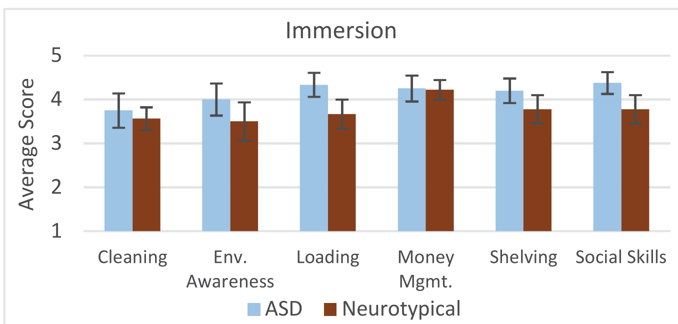

Fig. 14. Average immersion scores for the two user groups.

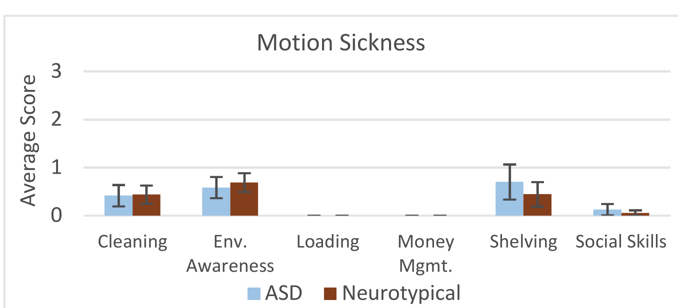

Fig. 15. Average motion sickness scores for the two user groups.

Immersion
As the question *"How immersed (feeling deeply included in) were you while training these skill tasks?"* was asked with choices ranging from "1: Not immersed at all" to "5: Immersed a lot," the results presented in Figure 14 were obtained. One-way ANOVA with repeated measures with $\alpha = 0.05$ for the immersion scores of individuals with ASD resulted in $F(5, 3) = 3.530$, $p = 0.079$, meaning that there was no significant difference between the immersion scores of different skills.

Motion Sickness
To measure motion sickness, the questions *"How nauseous/how dizzy do you feel?"* were asked with the choices ranging from "0: None" to "3: Major." The results of the two questions were averaged to obtain the motion sickness results, which are presented in Figure 15. As a one-way ANOVA with repeated measures was performed with $\alpha = 0.05$

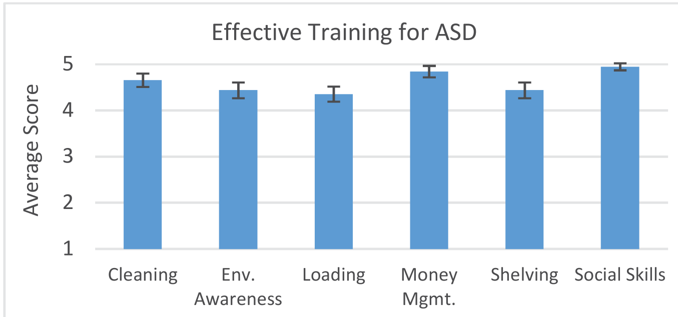

Fig. 16. Average effective training for ASD scores given by the job trainers.

for the motion sickness scores of individuals with ASD, the results were as follows: $F(5, 3) = 2.033$, $p = 0.216$, meaning that there was no significant difference between the motion sickness scores of different skills.

Satisfaction
All 18 participants (neurotypical and ASD) answered the question *"Would you come back to train with us again?"* as *"Yes."*

5.2.2. Job Trainer Data.

Effective Training
As the question *"Do you think that the VR4VR system will provide effective training for the trainees with ASD?"* was asked to the professional job trainers, with answers ranging from "1: Will not provide effective training at all" to "5: Will provide very effective training," they gave an average score of 5.00. As the question *"Do you think that the skill tasks will provide effective training for the trainees with ASD?"* was asked to the job trainers for individual skill modules with answers ranging from "1: Will not provide effective training at all" to "5: Will provide very effective training," the average scores were as presented in Figure 16.

Reasonable Design
As the question *"Do you think that the VR4VR system was designed and implemented reasonably?"* was asked to the job trainers, with answers ranging from "1: Not reasonably at all" to "5: Very reasonably," the job trainers gave an overall average score of 5.00. In the prior meetings with the job trainers during the design phase, the reasonable design and implementation of the system was interpreted as the individuals with ASD being able to operate the system and complete the tasks without spending too much cognitive or physical effort, as a neurotypical individual would operate such a system without any prior experience.

Accuracy
As the question *"Do you think that the VR4VR system was accurate in understanding the user's actions?"* was asked to the job trainers, with answers ranging from "1: Not accurate at all" to "5: Very accurate," they gave an overall average score of 5.00.

Follow-up Improvement Data
To assess the level of improvement the VR4VR system provided to the participants on the job skills trained, a follow-up questionnaire was given to the job trainers 1 month after the testing. The follow-up survey included the question, *"Please rate the level of improvement you saw in the participant after training with the VR4VR system for each skill."* with answers ranging from "1: No improvement" to "5: Major improvement." The

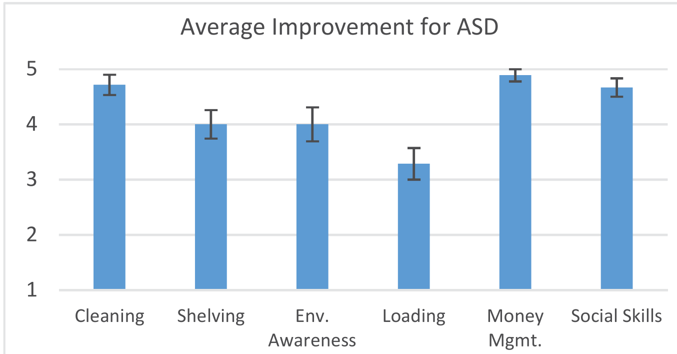

Fig. 17. Average improvement scores for individuals with ASD given by the professional job trainers.

participants who participated the user study were Florida's Vocational Rehabilitation (VR) services clients. Job trainers conducted several meetings with the participants afterwards to help them in getting employed, and hence they were able to observe the performance of the clients in real-world job settings after they trained with the VR4VR system (by completing each level of each skill module once). The average improvement results from the job trainers were as presented in Figure 17.

5.3. Survey Qualitative Data

The participants and the job trainers were also asked qualitative open-ended questions with the aim of further exploring the training experience that the VR4VR system provided. For *the most positive experience with VR4VR training,* five users with ASD stated that they enjoyed the technology involved and using the system in general. For *the most negative experience with VR4VR training,* five individuals with ASD stated that they had none while two individuals with ASD stated that the HMD made their eyes watery. On *whether they learned anything while training with VR4VR,* six individuals with ASD stated that they learned the cash register and the money-related skills, and two individuals with ASD stated they learned what a worker tends to do in general and how it was like working in a job environment.

As the job trainers were asked about *what they liked the most about the skill tasks*, five of them stated similar opinions on (1) the progression of levels, (2) gradually increasing difficulty, (3) allowing the participants to build on the learned skills step by step, (4) using a variety of distracters, (5) allowing the participants to look for details, (6) improving the participants' awareness and problem-solving skills, (7) using realistic supervisor employee dynamics, (8) applicability of the trained skills for many job positions, (9) relevancy to the real work experiences, (10) job-specific task training, and (11) safe and repetitive training. As they were asked about *what they liked the least about the skill tasks*, three of them shared similar opinions on the following: (1) some instructions not being as precise and literal as they could have been, since they could still have been interpreted differently by the participants; (2) difficulty of the loading-the-back-of-a-truck skill module for the individuals with ASD due to its requiring the users to fit the boxes into a tight space and tthus demanding too much cognitive effort; (3) difficulty of the third subtask of the environmental awareness skill module for the individuals with ASD in which the users were required to find the carts that were not in the cart collection area by walking around the parking lot; and (4) repetition of the assistive prompts too frequently, which created frustration on the users with ASD instead of the desired effect of helping them.

5.4. Post-Interviews

The research team had conversations with the participants with ASD on their opinions on the VR4VR system after they completed the training sessions. As the users were asked if they felt distracted while training with the VR4VR system, all participants stated that they did not feel distracted. As the users were asked about the possible reasons behind this, they consistently answered that they knew the distracters were not real. All of them said that they might have been distracted by some of these distracters in real life, but they had not gotten distracted in the VR system, since they knew all of what was happening was part of a virtual reality training game. Then we asked the participants if they thought that the distracters were applied realistically in the VR4VR system. They stated that they found most of the distracters realistic in the virtual world, but it did not matter, since they still considered them as virtual distractions. As we asked the participants with ASD the reasons behind their scoring immersion levels for many skill modules high, yet not getting distracted by the distracters, they stated that they were immersed in the game, but they still knew that it was a game. Hence, the interpretation of immersion by individuals with ASD was not as perceiving virtual environments, objects, and people as real but immersing themselves in playing a serious VR game while being aware that it was not real. These reviews shed light on why their scores in the levels without distracters did not significantly differ from the scores in the levels with distracters.

As we performed follow-up interviews with the job trainers about the usability of VR4VR system for job training in general, some of their comments were as follows: *"We saw great improvement in participants we brought in. Their job skills were improved especially in warehouse, money management and social skills." "The system is very helpful to see a participant's baseline and improve from there." "Many jobs require cash/money skills and need prior training. VR training is great for adults to learn cash register skills since real job places may hesitate to train employees with cognitive disabilities with real money."* They also stated that the technology involved in the VR4VR system was appealing for participants with ASD: *"Users with Autism enjoy interacting with technology. So VRVR is a great training tool for them. It is fun and interactive."*

6. DISCUSSION AND LESSONS LEARNED

6.1. Summary of the Results

The user study provided insight mainly on the performance of high-functioning individuals with ASD, improvement of the VR4VR system provided to individuals with ASD in the six job skills, and effects of the distracters on performance of individuals with ASD.

Level scores of individuals with ASD were significantly lower for the loading-the-back-of-a-truck skill. As we discussed the possible reasons with the job trainers, we found out the following: The loading-the-back-of-a-truck skill's design turned out to be too difficult for this population. The main reasons behind this difficulty were the low margin of empty space and the lack of broken-down steps. As an example, a participant was successful in putting in all of the first four of five boxes. However, when the fifth box appeared, if it did not fit to the remaining space, it required a rearrangement of all of the previously put boxes so that the correct configuration would be found. In the correct configuration, there was a 10% empty-space margin around the boxes. This was thought to overwhelm the participants with ASD and to yield the low scores received in this module. An alternative approach was suggested by the job trainers as follows: first, show the participants specific areas to put in the boxes and then gradually removing this form of help and expect them to fill the whole truck by themselves.

The job trainers thought that the most effective training would be provided by the social skills and money management modules and the least effective training would be provided by the loading-the-back-of-a-truck skill. As we discussed the reasons behind this, they stated that the social skills and the money management skills were designed such that they would apply to any job in real life, and individuals with ASD may lack training in these skills in real life. Although they thought that the remaining skills would also improve the relevant skills of the participants, they thought that these skills would require some additional training that is specific to job places afterwards (such as following specific steps for cleaning or putting the boxes on the shelves according to a different coding scheme). The job trainers saw the most improvement in participants with ASD who trained with the VR4VR system in the money management skills (4.89), followed by the cleaning (4.71) and the social skills (4.67). Average scores for all skills were above neutral (3.00), which indicated improvement in all skills and supported H1. However, the loading-the-back-of-a-truck skill received the lowest score (3.29) among the six skills. We think that this was caused by the insufficiently accommodating design of the module and will be addressed as future work following the possible solutions that were recommended by the job trainers.

Although many realistic distracters were implemented in the form of audio, visual, and two-dimensional and three-dimensional animation, there were no negative effects on the performance of individuals with ASD caused by these distracters. There was no significant difference in scores, rejecting H2. Interviews with the participants with ASD revealed that the reason behind this was the participants' always being aware of all stimuli's being only virtual and not real. This might have been caused by the characteristic of ASD stating that individuals have difficulty in projecting themselves into imaginary scenarios or environments [Dahl and Arici 2008].

Individuals with ASD stated high immersion scores for all skills. But when interviewed, they stated that they thought of immersion as immersing themselves in using the VR experience, not feeling themselves really present in the virtual worlds. Some users gave verbal responses to some events happening in the virtual environments, such as saying "Hi" to a virtual co-worker passing by or saying "Okay" in response to an announcement, but they still stated that they did not think of these as real situations but just virtual instances. This might also have contributed to the high scores received in the social skills module, since being aware that the experience was virtual would remove the social anxiety from conversation. Although a more detailed study analyzing immersion felt by individuals with ASD in VR is needed to make conclusions, we interpret that this might be related to the lack of imagination characteristic related to the ASD diagnosis. Although they might not feel like they are teleported into virtual worlds, virtual reality might still provide them with a good training tool in which they may train repetitively in a structured and safe environment. However, it should be noted that VR training may not create immersive experiences for this population as with neurotypical users and may not replace real-life training.

6.2. Lessons Learned

Several lessons have been learned by the research team throughout the study based on observations from the previous and the current testing sessions, several discussions with the job trainers, and interviews with the trainees. In this subsection, we share the lessons learned during not only the recent but also the previous user study sessions, with the aim of providing positive contributions to future VR applications targeting individuals with ASD.

Cash Register Skills

The users with ASD were asked the open-ended question *"Did you learn anything while training with our system? Please describe."* Six participants of nine stated that they learned cash-related skills, and they were very happy about it. None of these individuals have been previously recruited to cash-related jobs in real life. This provides an insight into the importance of cash register training opportunities for individuals with ASD. As we discussed with the job trainers, they stated that employers might be hesitant to provide training to individuals with ASD with real money, since the consequences might be significant to the business. They also stated that many jobs require cash/money skills and need prior training, and this constitutes a barrier for the number of jobs that are available for their clients with ASD. Hence, we believe that cash handling related training applications have significant value in providing training opportunities for individuals with ASD without using real money, since it is a required qualification for many retail-related jobs.

Creating Positive Feelings Toward the Experience

Getting a score of zero on the failed subtasks made the trainees with ASD considerably discouraged. We recommend shifting the scores up, so the minimum possible value is not zero. Positive reinforcements received positive feedback from the users with ASD and encouraged them noticeably. Using many positive reinforcements at the beginning and fading them out gradually to prepare the users for real life would be a good practice in training applications for individuals with ASD. Using words that might be misunderstood as being offensive turned out to be a bad practice in our study. VR4VR presented the users with a visual stating *"Subtask Failed"* at the end of the levels that the users could not complete successfully. The users got noticeably upset when they saw this visual. The job trainers later stated that the users might have interpreted that phrase as *"I am a failure"* and got discouraged. They advised us to use affirmative alternatives even in negative situations.

Frequency of Hints

The system provided automated assistive prompts once every minute if the users were unable to complete a requested task instance. This created a negative effect and made the users with ASD frustrated instead of helping them. The users did not pay attention to these hints. Some users gave verbal responses such as *"I know"* and *"I am trying."* We recommend providing seamless hints such as highlighting where to go or marking a wrongly fetched item as red instead of providing them frequent reminders of how to do the task at hand.

Brief Prompts

When providing prompts and pictographs to individuals with ASD, being very brief is of utmost importance. The directions should be as short and precise as possible. Otherwise the users with ASD might have difficulty in following the directions and stop following what is presented. In our VR4VR, simple pictographs that broke down the steps and gave clear directions such as "Do not throw fragile boxes from a large height" worked well, while more general ones such as "Put all of the boxes inside the back of the truck" did not. The users were able to understand what they needed to do in general, but to understand how they needed to do what was asked, they needed directions where the steps were broke down as much as possible.

Consistency

Even when the focus is on some another aspect, individuals with ASD might give importance to certain aspects such as alignment of objects when a task was learned. It

Fig. 18. Box labels. Left: Labels on the front face. Right: Labels on the top face.

is important to keep these aspects consistent throughout the whole experience if the intention is not to challenge them. In our VR4VR's shelving module's second subtask, the labels were projected onto the front of the boxes, whereas in the third subtask they were projected onto the top (Figure 18). Many users with ASD tried to rotate the boxes in the third subtask so their labels were matching the orientation of the ones in the second subtask. It did not matter for the sake of these subtasks how the users placed the boxes, but the confusion on the part of the users was not intended as part of the training. The job trainers suggested either changing the labels so their orientations matched or providing an instruction in the third subtask to provide a more effective training environment. This might relate to every unintentional change that could be part of a learning setup.

Breaking Tasks into Smaller Pieces
If a relatively complex task is expected from the user, then breaking down the task and teaching the user in small pieces can be a better approach. It is also important to present these pieces to the user with increasing difficulty. After the user gets comfortable with performing all of the small pieces, teaching them how to combine these small pieces into a large one step by step would decrease the stress. It is important to give the users space to practice on each of these small pieces and build on them in time via progressing levels. VR4VR's shelving module tutorials were demonstrated handling the orders and the deliveries with a single animation, explaining the whole process at once and training the users to perform the tasks this way. This did not work well, and shelving became the skill module that required the job trainers to frequently verbally explain to the user what they needed to do in smaller steps. Hence, the job trainers advised us to break down that tutorial and teach the task in smaller pieces. This idea should apply to any task teaching VR application targeting individuals with ASD.

Repetition
The literature and the job trainers state that individuals with ASD benefit from repetition of a learned task for reinforcement. Repetitive tasks might seem boring for neurotypical individuals and designers could put effort into avoiding this. But for individuals with ASD, repetition may provide valuable training, and they might even feel more comfortable when presented with repetitive tasks, since any form of change may make them uncomfortable. In our study, we observed these effects on the two populations. Neurotypical individuals showed various signs of boredom when performing several instances of the same task, while none of the individuals with ASD showed such signs of boredom. Hence, it is important to keep in mind that individuals with ASD do not get easily bored by repetition like neurotypical individuals and may benefit from performing various instances of the same task with repetition for reinforcement.

Well-Designed Breaks
In the more physically demanding skill modules of shelving and environmental awareness, some participants with ASD showed signs of tiredness in the form of body

language, verbal exclamation, and sweating. Although they were offered to take breaks, they stated that they wanted to continue until the module was finished. We interpret the motivation behind this as avoiding to break the routine, which is a known characteristic related to ASD. The job trainers then interrupted the module and gave mandatory breaks for them, since they did not find it good for them to continue exerting so much physical effort. After the module was finished, most of the participants stated in the surveys that they were not tired at all. So, designing frequent breaks that are tailored to the level of physical demand of the experience is very important while designing training applications for individuals with ASD, since they might be very driven to finish the task at hand and avoid breaking from the general routine.

Clarity and Literacy of the Instructions
As we observed from the testing sessions and the feedback from the job trainers, the instructions should be as clear and literal as possible. We encountered some instances in which the users with ASD interpreted the instructions differently. This did not mean that their interpretations were wrong; however, they were out of context for the designed tasks. An example was where the virtual instructor telling the user to vacuum clean the dry dirt piles and the user finding a small dark spot on the texture of an environmental wooden prop and trying to vacuum clean it for a long time. Hence, double checking the virtual environments for other possible interpretations might be a good guideline to follow to avoidi creating confusion in users with ASD.

Narrower Framework
In the loading-the-back-of-a-truck module, the users were required to fit the boxes into a tight space by changing their orientations (Figure 4). This created considerable stress and frustration on the users with ASD. The module did not have a structured nature, since the users were able to put the boxes in any way they wanted as long as all boxes fit into the back of the truck. This created a negative learning environment for individuals with ASD. They had difficulty in interpreting how to make all of the boxes fit into the provided space and how to progress. Instead of providing an open space, walking them through how to utilize the space with examples might have been a better approach in this case.

A similar case was observed in the environmental awareness module. In the first and the second subtasks, the users were required to navigate to the points that were marked with large green arrows that were visible from every spot of the virtual parking lot. In the third subtask, however, the users were required to find the carts that were not in the cart collection area. This time, the carts could have been occluded by the environmental props such as cars and trees, so the users needed to walk around the parking lot looking for the carts. Individuals with ASD struggled with the third subtask, although they did very well in the first and the second subtasks. We observed that they sometimes kept walking around the same spots instead of walking around systematically, and the subtask took considerably longer to finish for them. Again, a more structured guidance would have worked better in this case. To generalize this guideline, keeping a narrow and structured framework narrower and widening it gradually can be a better way of providing training to individuals with ASD instead of providing them with a larger framework in which they can experiment freely.

Different Attitudes
In the social skills module, some questions intentionally included difficult moods or informal words such as *“Why you think the workers don’t organize these damn boxes on the shelves?”* This caused some participants with ASD to laugh uncontrollably. The job trainers stated that this was a very valuable opportunity for them to train these

potential job seekers before they came across such instances in real life, probably with real customers instead of virtual ones. Hence, we recommend including extreme cases of human behaviors in social skills training modules for individuals with ASD to prepare them for these unusual cases of interaction and train them on how to handle these instances reasonably.

Irritation Caused by the Wearables
We observed that individuals with ASD got irritated by the hand markers and the easily fidgeting nature of the HMD—although they were not irritated by the concept of wearing an HMD. They frequently moved the marker bands and the HMD even when they were performing the tasks. When we asked the reason, they stated that they would prefer a very soft material for the hand bands and an HMD that would stay stable even when they turned or tilted their heads. Hence, we recommend using soft materials for any wearables and fastening the HMD or other wearables so they would remain as stable as possible.

6.3. Limitations

This study was performed with high-functioning individuals with ASD. Since Autism is a spectrum-based disorder, results of this study may not be applicable to the medium or lower parts of the spectrum. The population size of nine individuals with ASD was not as high to yield results with high statistical powers. This must be considered when generalizing the study results. The social skills module did not integrate many aspects of social interaction such as eye contact, conversation initiation, and maintenance. This should be considered in the interpretation of the results.

7. CONCLUSION AND FUTURE WORK

This article presents the VR4VR system, which utilizes six transferrable skill modules within immersive virtual environments for vocational training of individuals with ASD. The system was presented along with design considerations. User study results of nine neurotypical individuals and nine individuals with ASD was reported. Lessons learned were shared in the form of good design principles to provide positive contributions to future virtual reality applications targeting individuals with ASD. The follow-up surveys indicated improvement in individuals with ASD in all of the skills trained. Performance of the participants with ASD did not get effected by various virtual distracters. As found to provide effective training for individuals with ASD by the professional job trainers, we believe that our VR4VR system provides an alternative training tool for improving vocational skills of individuals with ASD. Although it would not replace real life on site job training given by job trainers, the system can be an effective assistive tool in quickly discovering a participant's characteristics and abilities, narrowing down the skills to train on, improving these skills by completing the VR training modules, and preparing the participant for the follow-up on-site training.

As future endeavors, the system is currently being updated according to the feedback collected from the job trainers and the participants during the user study sessions. The future exploration areas include using a new generation immersive HMD, developing a more comprehensive social skills training module, and developing mobile modules for training from home.

Many aspects of this user study yielded various possible areas to be explored for designing effective VR experiences for individuals with ASD such as perception of immersion and forms of information presentation. For that purpose, we will be designing and implementing new VR experiences and evaluating them with participants with ASD with the aim of providing more-generalized VR design guidelines for this population.

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