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Personalized Training via Serious Game to Improve Daily Living Skills in Pediatric Patients with Autism Spectrum Disorder

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***Abstract*—The majority of people with Autism Spectrum Disorder (ASD) exhibit difficulties in social communication and behavior, which hinder their learning capability, amid others. Among technological solutions for people with ASD, serious games are frequently used to enhance learning of specific skills and instructional contents. However, because of heterogeneity in applications and game design, few studies have investigated their use in training daily activities. This paper presents a 3D personalized serious game we developed and validated to help ASD patients practice with shopping activities. Personalized training is paramount in people with ASD, thus several elements of this game were personalized to improve engagement and therefore the effectiveness of the virtual training. In order to assess the validity of the game, ten subjects (age 11.9 ± 2.7, 20% female) with ASD played ten sessions of the serious game, once per week. The participants underwent a real-life experience pre- and post-training in a real-life supermarket. Changes in daily living skills among participants were evaluated through specific tools: a form based on the International Classification of Functioning, Disability and Health for Children and Youth; and the Vineland Adaptive Behavior Scale II. Significant improvements ($p<0.05$) were detected in the main skills trained with the serious game, especially in learning the shopping procedure, directing attention, and problem-solving skills. These findings suggest that personalized serious games can represent a prominent tool to enhance daily living skills, but future work should clinically validate their efficacy.**

***Index Terms*—serious games, Autism Spectrum Disorder, daily living skills, human-computer interactions**

I. INTRODUCTION

AUTISM Spectrum Disorder (ASD) encompasses a set of neurodevelopmental disorders clinically characterized by two main categories of symptoms: deficits in social communication and social interaction; restricted patterns of behaviors [1]. Due to the variability of the degree of impairment in these symptoms, the Diagnostic and Statistical Manual of Mental Disorders fifth edition (DSM-V) [1] defined three severity levels based on the required support: Level 1 (Requiring support), Level 2 (Requiring substantial support), and Level 3 (Requiring very substantial support). Beyond the two main symptom categories, ASD can occur with intellectual disability and other associated comorbidities [1]–[3]; moreover, ASD symptoms appear in early childhood and can change over the years with diverse developmental pathways [4]. Therefore, there is high heterogeneity in ASD clinical presentation.

As shown by longitudinal studies [5], [6], the majority of adults with ASD are not independent and present serious problems in the adaptive functioning domain, especially in daily living activities [7], [8]. These problems were also detected in those who have average and above average intelligence [9] and depend on disorder features, particularly deficits with executive functions, behavioral inflexibility, difficulties in the generalization process, possible sensory issues and motor impairments [10]. Daily living skills difficulties turn into a sustained demand of continuous assistance by parental caregivers, consequently increasing their burden [11] and costs associated with ASD [12].

Technological developments have been providing new tools and strategies for helping people with ASD learn and train skills [13]. In particular, a growing number of studies [14], [15] explored the use of instructional videogames, better known as serious games (SGs), as training tools to enhance skills in people with ASD. SGs are defined as digital games designed to achieve specific learning purposes [16]. They usually consist of at least three factors: 1) simulation, because they can reproduce real events or some aspects of real events; 2) learning, because the main purpose of SGs is to acquire and train skills and knowledge; 3) the game itself, because SGs have the structure of actual videogames [17]. The spread of SGs in the ASD domain is facilitated by the affinity of people with ASD with technology [13] and their high interest in videogames [18]. Furthermore, SGs promote a designed learning experience that can respond to different needs of players with ASD and facilitate the generalization process [19].

SGs showed good outcomes in people with ASD, especially for emotion recognition [14], [15], [20], social skills [14], [21], and cognitive skills [22]–[24]. Nevertheless, few studies [25]–[28] have investigated SGs usage in training daily living skills for people with ASD and their applications were very different in this domain. For instance, Kang and Chang [27] developed a 2D game for children with ASD aimed at learning to take

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a shower. Their study involved six children with ASD and showed positive results in the accuracy of the selected tasks required for a shower. Simões *et al.* [28] developed a 3D SG with a VR headset to help young adults with ASD learn how to take the bus. After three game sessions, the ten participants showed improvements in the theoretical knowledge of the process and a decrease in the anxiety felt during this activity.

Beyond the limited number of studies and restricted topics, it is worth pointing out that SGs targeting the training of daily living skills do not usually feature a personalized design nor implement individualized elements into the game, despite the relevance of this factor. According to the ASD International Guidelines [29]–[31], it is highly recommended to carry out individualized programs and interventions, including technological ones, in order to respond to the heterogeneity of ASD. That is why several studies [14], [15], [19], [32], [33] have emphasized the importance and need to implement an individualized approach even in SGs design.

The aim of this study is to investigate the feasibility of virtual training through a personalized SG on a specific daily living activity: shopping in a supermarket. The underlying hypothesis of this study is that training with an individualized SG can improve the learning and practice of skills useful to a shopping activity, promoting the generalization of these skills to a real-life environment. In order to prove this hypothesis, a sample of ten subjects with ASD played a personalized SG, *ShopAut 2.0*, for ten sessions. Subjects underwent real-life experiences in a supermarket pre- and post-virtual training to evaluate possible changes in the trained skills and to determine whether there had been a transfer of skills from the virtual environment to the real environment. The assessments of the SG-based training considered both the changes in the participants' performance during the real-life experiences, which were evaluated using a specific form based on the International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) [34] framework; and the changes in scales of the Vineland Adaptive Behavior Scale II (VABS-II) [35].

The remaining part of this paper is organized as follows: the Methods section provides a detailed description of the experiment setup, explaining how participants were selected, the procedure, the SG design, the data collection process, and our statistical analysis. The Results section shows the outcomes obtained and the analyses performed. The Discussion section discusses the results of our SG-based training, pointing out our novel contributions in the context of existing literature, as well as our study's limitations. Finally, the Conclusion section provides a summary of the present work, offering a conclusion and hinting at plans for future works.

II. Methods

A. Participants

Ten children and teenagers with ASD were recruited from patients diagnosed at the Department of Translational Medical Sciences, University of Naples Federico II, which follows a rehabilitation program at the medical center Centro Medico Riabilitativo Pompei. The study was in accordance with the declaration of Helsinki and it was approved by the Ethics Committee of the University of Naples Federico II (Reference number: 98.20/2020, date of approval 20/05/2020).

TABLE I
Characteristics of participants.

Participant	ASD Severity Level	Sex	Chronological Age	FSIQ[a]
P1	L1	M	11	93
P2	L1	M	8	93
P3	L2	F	16	58
P4	L2	F	12	58
P5	L2	M	10	57
P6	L2	M	16	53
P7	L3	M	12	50
P8	L3	M	11	45
P9	L3	M	14	40
P10	L3	M	9	40

[a]FSIQ= Full Scale Intelligence Quotient, estimated via the Wechsler Intelligence Scale for Children IV (WISC-IV).
The table summarizes the main features of the participants, reporting ASD severity level evaluated through a diagnostic screening, sex, chronological age, and Full Scale Intelligence Quotient (FSIQ).

Inclusion criteria were: 1) clinical diagnosis of ASD, in keeping with the diagnostic criteria of DSM-V [1]; 2) chronological age between 8 and 16 years; 3) native Italian speakers; 4) a rehabilitation plan already underway in accordance with the study's goals. At baseline, the participants' IQ was estimated via the Wechsler Intelligence Scale for Children IV (WISC-IV) [36] and a diagnostic screening was conducted via Autism Diagnostic Observation Schedule-Second Edition (ADOS-2) [37] to evaluate their severity level in compliance with the DSM-V [1]. Table I summarizes the characteristics of the participants.

B. Procedure

Our multidisciplinary team elaborated a specific experimental protocol for this study, identifying three steps:

1) Baseline real-life assessment: first real-life experience to evaluate the participants' performance in a real environment.
2) Training: virtual training with the individualized SG to train, experiment, and practice behaviors and actions.
3) Final real-life assessment: second real-life experience to evaluate the potential improvements achieved by the participants after the training.

In the real-life experiences, the participants went to a supermarket accompanied by a therapist, while a researcher recorded the experience with a traditional camera. During the real-life sessions, the therapist guided the participant, providing him or her with a shopping list that included three tasks to complete: pick up the ingredients to cook a dish (pasta with tomato sauce); pick up personal care products; pick up a product to organize a party. The tasks in the shopping list were both written and explained with representative images. The therapist supported the participant only where necessary. The real-life experiences were interrupted when the participant showed critical behaviors to avoid excessive stress. The videos of real-life shopping sessions were analyzed independently by two research members, a psychologist and a neuropsychiatric, who had not been involved in the real-life sessions. The two independent observers were aware of the time point for the shopping sessions they rated.

The virtual training with the SG took place during the therapy session of the participants at the rehabilitation center. The game sessions were led by each participant's therapist, who chose the game options via a menu according to each participant's needs, with a researcher supervising in case of a technical issue with the game. The therapists only supported the players when necessary or required without influencing their performances during the game sessions. Each participant started their SG-based training from the first game level and played ten game sessions, one per week, for no more than 30 minutes.

C. Game Concept

Our SG, *ShopAut 2.0*, was a three-dimensional game conceptually based on classic 3D life simulation games. It was devised for Italian players and implemented graphics that were friendly for children and teens. *ShopAut 2.0* aimed to teach players the procedure of a shopping activity; to reinforce object categorization and recognition in a supermarket; to improve attention, orientation, and problem-solving skills; and to help the player engage in simple economic transactions.

The game was developed by integrating an individualized design that combined customization (intended as a way to let the player choose and configure their own game experience) and personalization (that is a static adaptation of the game to the needs of the player) [16]. In both cases, individualized features were implemented statically within the SG. Regarding customization, before launching the game, the main menu allowed the therapist, or a generic external user that assists players with ASD, to select: the game level, the game mode, and the type of player according to the needs and preferences of the users with ASD. Instead, the personalization involved the games contents, scenario, difficulty, and user interface.

From a design point of view, *ShopAut 2.0* consisted of ten levels with different game missions of increasing difficulty, the first one being a tutorial level meant to introduce the player to the game. The player was awarded a gold, a silver or a bronze medal at the end of each game level, depending on the final score. To calculate the game score, as advised by [28], we drew up a checklist with all the different actions involved in a shopping experience, and we calculated the score based on the accuracy percentage for these actions. The player could only access the subsequent level from the main menu if they earned a medal; otherwise, they had to play the same level again.

The mode option provided three game modes based on DSM-V severity levels [1]: mode 1 for ASD Level 1 that requires support; mode 2 for ASD Level 2 that requires substantial support; mode 3 for ASD Level 3 that requires very substantial support. Support was offered within the game through game facilitators and depended on the game missions and difficulty. For instance, in the first few levels where the main task was to buy specific products, game mode 3 directed the player to the preferential route through arrows and lights, and visual and audio cues were given when necessary in order to draw the player's attention. Moreover, the shopping list included helpful images and the products to buy were highlighted by colorful lights to facilitate recognition. Instructions were conveyed through written, visual and audio messages. This feature of the game modes was designed to adapt the game to the player without changing the game flow or the game itself, and to prevent the player from experiencing a feeling of inefficacy or frustration in completing the game [19].

The menu option for the type of player allowed users to choose between a first- and a third-person view. In Fig. 1, it was reported the third-person view. Moreover, two input devices could be chosen: joystick controller or keyboard with mouse. Customization of perspective and input devices was provided to enhance accessibility and usability of the game. The game contents were designed to be clear to players with ASD, taking in consideration their needs in acquiring knowledge (e.g., decomposing complex actions, avoiding fictional narratives, inserting motivating elements, increasing gradually game difficulties) [15], [19], [32], [33] and ASD severity levels. Moreover, *ShopAut*'s game structure and learning contents were developed on real-life shopping activities and possible real-life situations to provide a realistic virtual training and improve the transfer of skills from the virtual environment to the real environment [33]. Accordingly, to further support generalization, we personalised the scenario by reproducing the same real-life supermarket, so that the SG-based training not only showed the different tasks and improved the required skills to perform them, but also made the real-life setting predictable. Abundant literature [29]–[31] demonstrated that making the environment predictable can reduce anxiety and resistance correlated to new situations and conditions in people with ASD.

The game difficulty was personalized based on the game mode and increased with the progression of the game levels. Therefore, the first game levels allowed the players to understand the game and its dynamics. As the players became more expert, new challenges were introduced in order to maintain engagement and motivation, and other contents were integrated in order to improve different skills [19]. In particular, new challenges were introduced in the game every three levels and they depended on the number and type of the tasks provided in the shopping list, and involved the introduction of unexpected events and sound distractors, the complexity of economic transactions, and the interaction with avatars. For instance, Levels 2, 3, and 4's shopping list had only one task; Levels 5, 6, and 7 required two tasks; Levels 8, 9, and 10 required three tasks. However, the tasks themselves varied for each level and their difficulty increased gradually. Similarly, the complexity of economic transactions increased linearly among game levels, from selecting only two coins to calculating the rest. Starting from Level 5, realistic audio and unexpected events were introduced. Starting from Level 8, interactions with avatars were required.

The user interface had a simple design, showing written messages and images. More specifically, the written messages appeared in a separate panel on top of the screen for game missions/instructions (Fig. 1), at the bottom for dialogues, and

Fig. 1. Screenshot of the third-person view in *ShopAut 2.0*. The image shows how the game is viewed when the player selects a third-person perspective. The player does not control the camera, which automatically follows the player character.

in the middle for feedback, whereas the shopping list was in the upper left of the screen. These messages were aided by images in first few game levels and in game modes that required more support.

ShopAut 2.0 started by introducing a character who asked the player to help him buy certain products from his shopping list. Buying products was the main mission, but other sub-missions were provided during the game. The game took place in two environments: the supermarket and its parking lot. The player was allowed to move everywhere in the scenarios and to interact with any objects that could be useful. In addition, the shopping game experience was also interactive, with the player being allowed to select the products they intended to buy through a fictional barcode scanner on the shopping cart. A feedback system was present in the game in the form of sounds and textual messages based on the accuracy of the player's actions.

The game was developed using Unity [38] (version: Unity 5.6.6 Personal 64 bit for Microsoft Windows) as a game engine. The game objects were downloaded from the Unity Asset Store or they were modelled using 3D Studio Max [39], in case of specific characterizing objects. Autodesk Character Generator [40] and Mixamo [41] were chosen for creating and animating the characters, respectively. *ShopAut 2.0* required a PC with Windows 10 Home 64 bit, 16GB RAM and Intel Core i5 7th Generation in order to guarantee the best performance.

D. *Outcome Measures*

For the assessments of the SG-based training, two main outcome metrics were considered: a form based on the ICF-CY [34], used to evaluate the participants' functioning in real-life experiences, and a standardized assessment tool, the VABS-II [35], to rate the participants' ability to perform daily activities.

To create the ICF-CY form, following the ICF-CY user instructions [34], we identified each shopping action and each involved component, and we classified the information related to them within the ICF-CY codes of the Activities/Participation component. This component was chosen because it concerns the domains related to the execution of activities and the involvement in real-life situations. Shopping in a supermarket can be identified mainly in the ICF-CY code d6200, but it is a procedural activity that requires completing multiple tasks (d2201) and involves different skills that can be represented by specific ICF-CY codes. Indeed, it requires: intentionally maintaining attention to specific actions (d161); the functional use of specific skills, such as reading (d166) and receiving messages (d310 and d315) with the purpose to obtain specific information; problem-solving (d175); decision-making (d177); self-regulation and self-control (d250); coordinated hand (d440) and arm (d445) motor actions; walking and moving in different places (d460); relating with strangers (d730); and engaging in any form of economic transaction (d860).

To code the selected ICF-CY codes, we adopted the qualifier *performance*; this qualifier represented the involvement of an individual in a real-life situation. The score of our form followed the ICF-CY scale for the *performance* qualifier. This scale encompassed five levels: 0 (no difficulty); 1 (mild difficulty); 2 (moderate difficulty); 3 (severe difficulty); 4 (complete difficulty). Moreover, the scale provided two additional values: 8 (not specified), which was used when there was insufficient information to specify the severity of the difficulty; and 9 (not applicable), which was used when no specific ICF-CY code was suitable.

Besides identifying the ICF-CY codes, we observed that some of them depended strongly on the shopping actions. Therefore, we structured the form around the idea that the shopping actions represented the items to be evaluated in order to code these specific ICF-CY codes. Since different actions of a shopping experience belonged to the same ICF-CY code, we gathered these actions in a group of five (or one of its multiples) to facilitate scoring; in this case, the score of the ICF-CY code was the median of the provided items. However, if a score of 8 or 9 was assigned to less than half the items, those scores were not considered for the median; otherwise, a score of 8 or 9 had to be assigned to the ICF-CY code. When the median was calculated between even numbers of items, the score was rounded up if it was ranging between two values of the ICF-CY scale. We followed the traditional coding for other ICF-CY codes that were not correlated to specific actions.

Furthermore, environmental factors were coded for each ICF-CY code in accordance with the ICF-CY coding convention 3 [34], provided for the Environmental Factors component. In this case as well, the ICF-CY scale for the Environmental Factors component provided by the ICF-CY was followed: a 0-4 scale was always used for barriers (0 = no barrier to 4 = complete barrier); for facilitators, the same 0-4 scale could be used (+0 = no facilitator to +4 = complete facilitator), but the point was replaced by a plus sign. The full form was reported in Supplementary Table I.

The effects of the training on daily living skills were also assessed clinically via the VABS-II [35]. The VABS-II consisted in a semi-structured interview with the parents, organized in the following functioning domains: Communication, Daily Living Skills, Socialization. Higher VABS-II score indicated better adaptive functioning. The VABS-II was carried out both pre-training (during the diagnostic screening of the participants) and post-training (after the second real-life sessions, at six months from the first VABS-II assessment).

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E. Statistical Analysis

The inter-rater reliability of the ICF-CY scores was calculated from the data, obtained from two independent observers via weighted Cohen's kappa [42]. Cohen's kappa was calculated with 95% confidence. ICF-CY codes that scored 8 or 9 were considered missing values in the statistical analysis. The comparison of paired data (pre- and post-training) was analyzed via the Wilcoxon signed-rank test. Since the present study is an exploratory study, we did not account for multiple testing in our statistical analysis. The statistical analysis was conducted using R Software [43] and a p-value < 0.05 indicated statistically significant differences.

III. Results

In the first real-life shopping experience, four participants (p4, p5, p7, and p10) did not complete their shopping as they encountered various difficulties, especially in managing their own behavior, directing their attention, and understanding the tasks; in these cases, the experience was interrupted not to upset the individual. Participants p1 and p8 did not have a chance to interact with others, including cashiers - who constitute a typical interaction with strangers in a supermarket - as there were none on that day, and they had to rely on self-checkout machines instead. In this case, the cashier's actions were performed by the therapists. During the virtual training sessions, the participants did not show any problems using the SG and they gained a game medal in each game session. They were drawn to the game from the start, asking to replay it, highlighting the variations among the game levels, trying to achieve the highest score, or voicing their impressions about the game. After the training with *ShopAut 2.0*, all participants completed their shopping activities, showing greater self-confidence and self-control during their second shopping sessions. Even in this experience, p8 did not engage in temporary contact with strangers.

The videos of the real-life shopping sessions were analyzed separately by two authors to determine ICF-CY code scores. Cohen's kappa statistic was used as the measure of inter-rater reliability. The results of Cohen's kappa statistics presented an almost perfect agreement between the two observers both pre- (κ = 0.96) and post-training (κ = 0.90). For this reason, we adopted the raters' median as the only actual ICF-CY score. No ICF-CY codes were evaluated with a score of 9, which would have suggested an unsuitable ICF-CY code, whereas some codes were rated 8 because the observers did not have sufficient information to assign a score, especially in the first real-life experience. These last scores were considered missing values in the statistical analysis.

Overall, all participants showed a scoring decrease post-training, as shown in Fig. 2, Fig. 3 and Fig. 4; this decrease indicated that participants exhibited less difficulty in the selected ICF-CY codes. The Wilcoxon signed-rank test of the ICF-CY data showed statistically significant differences between pre- and post-training for all ICF-CY codes of ICF-CY Chapter 1 on Learning and applying knowledge (p_{d161} = 0.004, r = 0.875; p_{d166} = 0.017, r = 0.793; p_{d175} = 0.007, r = 0.846; p_{d177} = 0.011, r = 0.806); for all ICF-CY selected codes of ICF-CY Chapter 2 on General tasks and demands (p_{d2201} = 0.006, r = 0.855; p_{d250} = 0.011, r = 0.807); and for the ICF-CY code d6200 from ICF-CY Chapter 6 on Domestic life (p_{d6200} = 0.004, r = 0.877). Significant differences pre- and post-training were detected only for the code d310 (p_{d310} = 0.011, r = 0.806) of ICF-CY Chapter 3 on Communication (p_{d315} = 0.186, r = 0.499). Similarly, a statistically scoring decrease was detected only for codes d445 (p_{d445} = 0.036, r = 0.707) and d460 (p_{d460} = 0.004, r = 0.875) of ICF-CY Chapter 4 on Mobility (p_{d440} = 0.087, r = 0.609). For the codes of ICF-CY Chapter 7, on Interpersonal interactions and relationships, and 8, on Major life areas, statistical differences were not detected between pre- and post-training scores (p_{d730} = 0.500, r = 0.500; p_{d860} = 0.074, r = 0.707).

As for the Environmental Factors component, according to the ICF-CY convention 3, the observers indicated potential facilitators and barriers for each ICF-CY code. In particular, the possible support of the therapist (e.g., showing a task) during the real-life experiences was identified by the observers as a facilitator and it was classified with the ICF-CY code e355. Even then, the agreement level on the score was evaluated via Cohen's kappa and we detected a total agreement on the score (κ = 1) both pre- and post-training. The Wilcoxon signed-ranked test reported a statistically significant decrease between pre- and post-training for all the ICF-CY codes (p_{d161} = 0.005, r = 0.864; p_{d166} = 0.045, r = 0.662; p_{d175} = 0.016, r = 0.760; p_{d177} = 0.024, r = 0.702; p_{d2201} = 0.010, r = 0.775; p_{d250} = 0.027, r = 0.699; p_{d310} = 0.027, r = 0.699; p_{d460} = 0.006, r = 0.857; p_{d6200} = 0.013, r = 0.766), except for d315 (p_{d315} = 0.173, r = 0.5), d440 (p_{d440} = 0.500, r = 0.354), d445 (p_{d445} = 0.087, r = 0.609), d730 (p_{d730}= 1.000, r = 0) and d860 (p_{d860} = 1.000, r = 0). Regarding barriers, the observers reported some difficulties to clearly identify their impact on the participants' performance for each ICF-CY code. They indicated sounds (e250) as possible general barriers in the shopping experience, but they managed to properly code only the former for some participants. The dataset of the ICF-CY codes and their Environmental Factors was uploaded to IEEE DataPort (DOI: 10.21227/v86n-n454).

Similarly, we used the Wilcoxon signed-rank test also to compare both pre- and post-values of the VABS-II scales. In this case, we once again detected significant improvements in all the VABS-II scales: Communication (p = 0.037, r = 0.614), Daily Living Skills (p = 0.004, r = 0.856) and Socialization (p = 0.012, r = 0.711). The VABS-II scores were reported in Fig. 5.

IV. Discussion

In the context of SGs targeted at people with ASD, learning and generalization of trained skills, specifically daily living skills, were evaluated by various approaches [27], [28]. The current study was the first to use an observational form based on the ICF-CY framework [34]. The elaborated form allowed us to identify the ICF-CY codes involved in the shopping experience, including both needed activities and required skills. However, the form we devised evaluated qualitative variables derived from both behavioral observations and the actions

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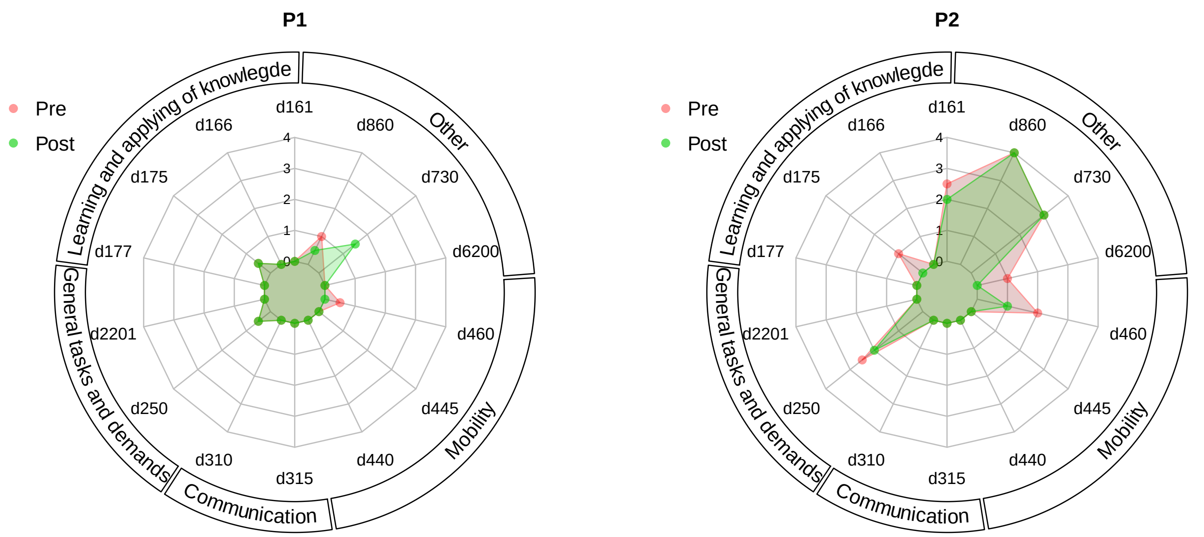

Fig. 2. Pre- and post-training ICF-CY profiles for ASD severity level 1 participants. The figure shows the ICF-CY profile of each participant with ASD level 1. The axes of the graph represent the different ICF-CY codes, which were evaluated during the real-life experiences through the elaborated form. On each axis, the red dots represent the ICF-CY scores in pre-training, whereas the green dots are for post-training. Following the ICF-CY scale, the values encompass five levels: from 0 (no difficulty) to 4 (complete difficulty). A dot not appearing on the axis means that there are missing values for that axis, corresponding to a score of 8 in the ICF-CY scale. The corresponding area of belonging to ICF-CY chapter for the main ICF-CY codes was reported.

performed in real-life experiences. For this reason, the real-life experiences were analyzed by two expert observers to establish the consistency of the ICF-CY scores. The inter-reliability analysis indicated an almost perfect level of agreement between the raters. This result highlights the reliability of our form, which appropriately identified the activities and behaviors involved in the shopping experience.

Overall, in the first real-life shopping session, the majority of participants were disoriented, insecure and, above all, distracted, being unable to focus their attention throughout the shopping activity; and some of them (p4, p5, p7, and p10) did not complete the shopping sessions. In particular, as reported in Fig. 2, Fig. 3 and Fig. 4, all participants, except p1 and partly p2 and p6, showed notable levels of difficulty in almost all ICF-CY codes, despite facilitations offered by therapists. After the virtual training with the SG, all participants completed the shopping experience, showing increased attention, orientation ability, self-confidence, and knowledge of the shopping procedure. In fact, all participants exhibited better scores in the monitored ICF-CY codes (Fig. 2, Fig. 3 and Fig. 4) and the analysis of paired data confirmed statistical improvements for most ICF-CY codes. Moreover, these improvements were confirmed by the decreasing support of the therapists, as well as by the statically significant changes in the VABS-II (Fig. 5).

With reference to ICF-CY Chapter 1 on Learning and applying knowledge, decreases in the level of difficulty were reported in all ICF-CY codes for all participants after the virtual training, expect for p1 and partially p2 and p10 (Fig. 2, Fig. 3 and Fig. 4). The statistical analysis showed significant changes in all the ICF-CY code of this chapter, with a statistically significant decrease in therapist's facilitators. The virtual training helped participants to maintain their attention on specific tasks (d161), consequently improving their concentration in performing different actions. This result is consistent with a recent study proposed by Macoun *et al.* [22], in which twenty students with ASD (aged 6-12 years) showed progress in selective attention after training with a SG over 8-10 weeks for 12h. Moreover, the virtual training enabled the participants to exercise reading skills (d166) in a functional way, or rather, for the purpose of obtaining information, such as reading the instructions in the environments to orientate themselves or to locate the desired products among different aisles. Even in earlier studies [23], [24], children with ASD (aged 6-11 years) showed improvements in acquiring literacy skills after SG-based training. However, unlike these previous studies, the present study did not address literacy skills, but was focused on training reading skills in order to apply them in a shopping activity. Furthermore, *ShopAut 2.0* was useful to enhance problem-solving skills (d175) in the participants; in fact, during the virtual shopping sessions, players had the opportunity to analyze a variety of real-life issues related to the shopping activity, including understanding the number of shopping bags based on the bought products, solve easy math problems or handle unexpected situations. Similarly, another earlier study [21] found progress in social problem-solving skills in children with ASD (aged 5-8 years) after ten game sessions. We noted improvements also in the code d177, relating to decision-making. The virtual training represented a mental workout where players received useful information to make a decision, evaluated the potential alternatives of a choice, and experimented the possible consequences of their decisions. In this way, during the second real-life experience, participants appeared more self-confident in making required decisions, such as selecting products out of two or more alternatives or evaluating the task to be performed based on their actions. The good outcomes in the area of Learning and applying knowledge were also confirmed by the paired data analysis of the VABS-II (Fig. 5), specifically, by the Communication scale that involves items related to attention

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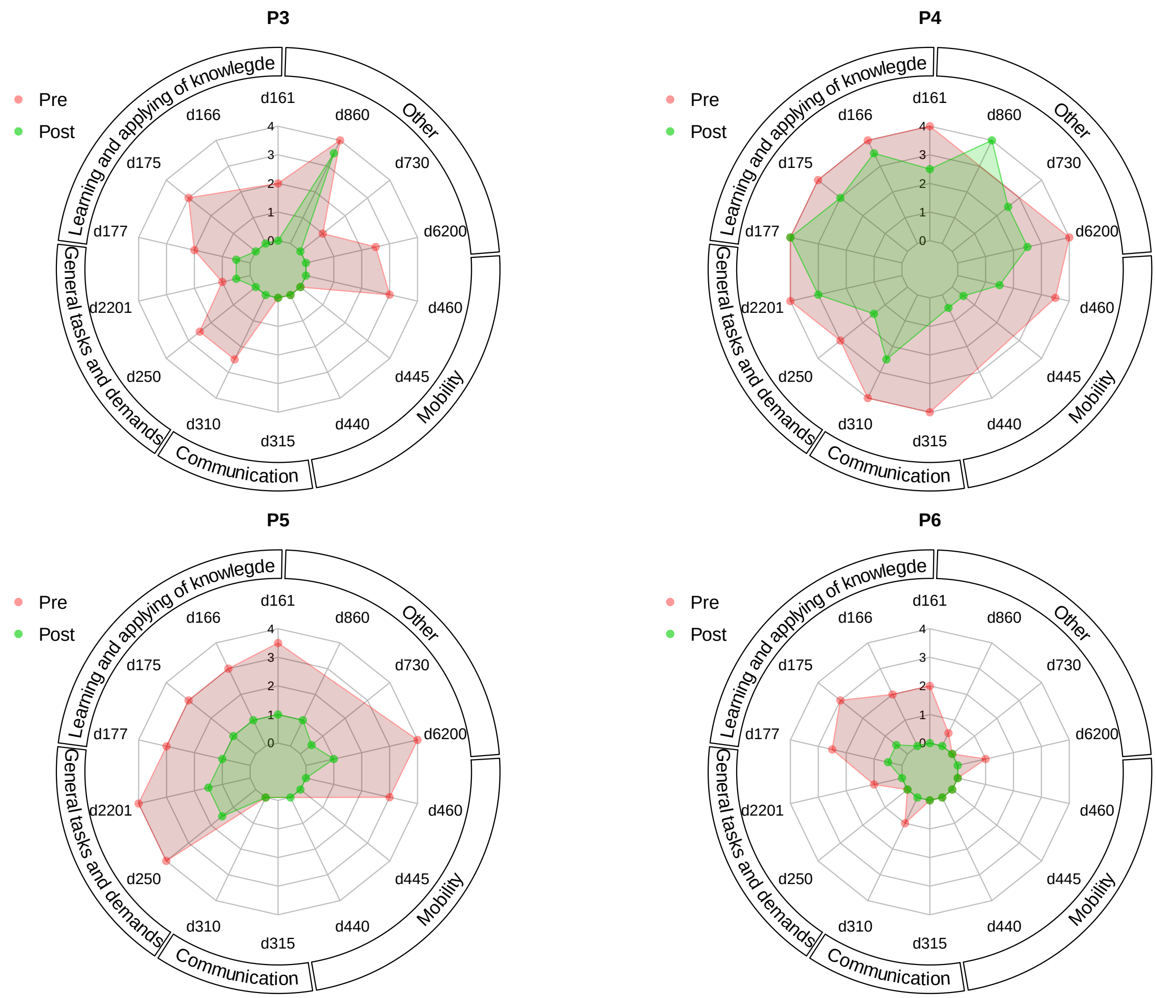

Fig. 3. Pre- and post-training ICF-CY profiles for ASD severity level 2 participants. The figure shows the ICF-CY profile of each participant with ASD level 2. The axes of the graph represent the different ICF-CY codes, which were evaluated during the real-life experiences through the elaborated form. On each axis, the red dots represent the ICF-CY scores in pre-training, whereas the green dots are for post-training. Following the ICF-CY scale, the values encompass five levels from 0 (no difficulty) to 4 (complete difficulty). A dot not appearing on the axis means that there are missing values for that axis, corresponding to a score of 8 in the ICF-CY scale. The corresponding area of belonging to ICF-CY chapter for the main ICF-CY codes was reported.

and reading skills.

The statistical analysis showed considerable differences pre- and post-training in all the selected ICF-CY codes for the ICF-CY Chapter 2 on General tasks and demands, with minor support provided by the therapist. More specifically, in the second real-life experience, improvements were observed in the participants' ability to complete multiple tasks (d2201), excluding p1 and p2 (Fig. 2). Our SG was a useful tool both to decompose the composite activities of shopping in single steps and to illustrate the sequence of tasks to follow. These findings are in accordance with previous studies [27], [28] that proved that SG-based training can be useful for people with ASD to train procedural knowledge and task accuracy in daily living activities. SGs enable people with ASD to identify and practice all tasks required by day-to-day activities step by step, helping them learn and apply those steps. As proved by results related to the ICF-CY code d250, the participants that showed difficulty in the first experience became more adept at managing their own behavior in the social context of a supermarket after the virtual training. Training with *ShopAut 2.0* enabled participants to familiarize with the shopping activity, to make the supermarket environment predictable and to understand the social dynamics at play, mitigating possible feelings of anxiety and fear, self-stimulatory behaviors, hyper- or hypo-reactivity to sensory inputs. It should be noted that problems in behavior in response to different social situations represent a clinical ASD hallmark [1], so changes in this code are relevant to prove the feasibility of personalized SG-based training for people with ASD. These improvements were also reflected in the analysis of the VABS-II Socialization scale (Fig. 5), where changes in social aspects were investigated, including impulse control and social behavior.

As hypothesized, significant improvements were identified in the ICF-CY code representative of the general shopping experience: d6200. As shown in Fig. 2, Fig. 3 and Fig. 4, except for p1 who had no difficulty even in the first real-life session, all participants showed better outcomes in their performance. Significantly, some participants (p4, p5, p7, and p10) did not complete their shopping session during the first experience, but all participants carried out their shopping post-

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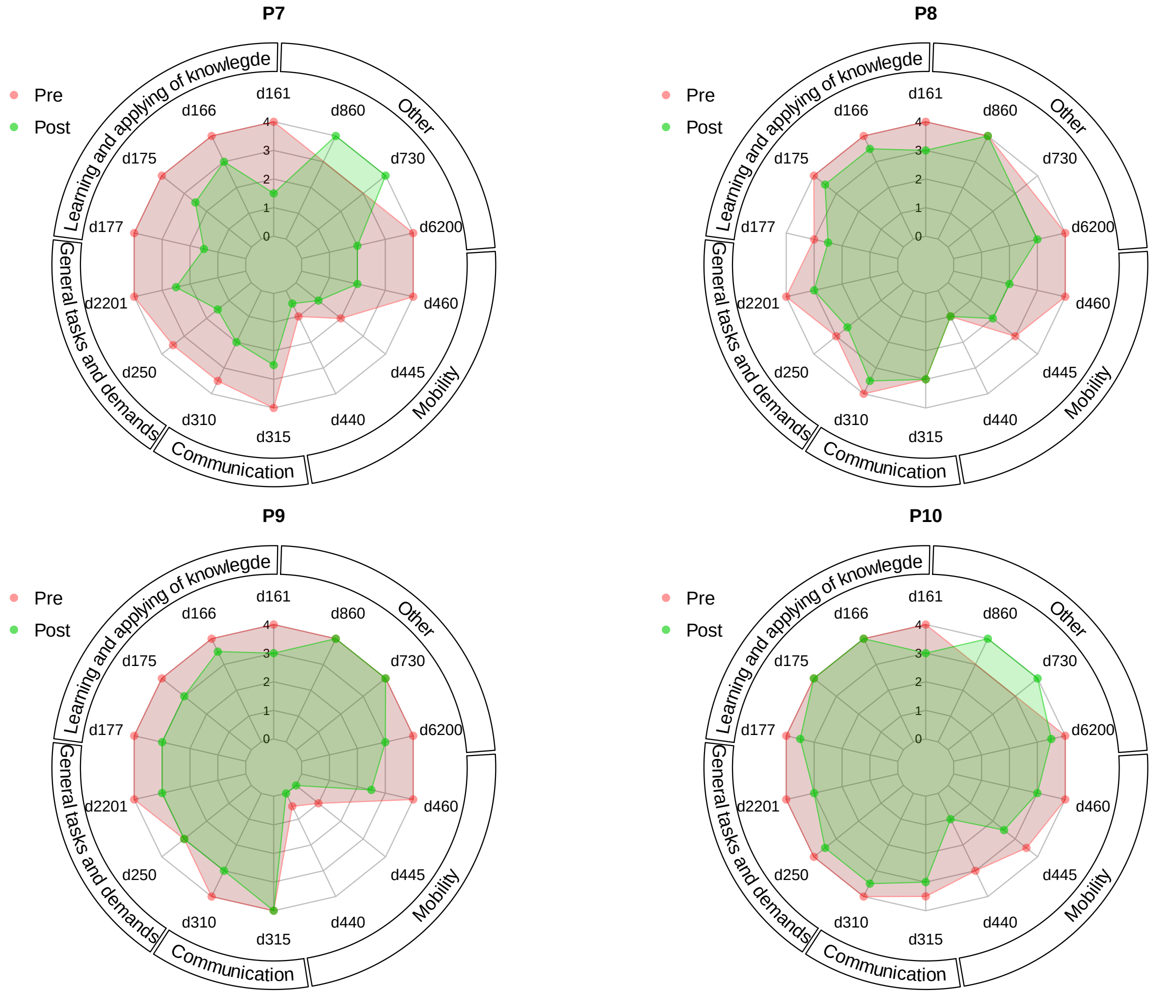

Fig. 4. Pre- and post-training ICF-CY profiles for ASD severity level 3 participants. The figure shows the ICF-CY profile of each participant with ASD level 3. The axes of the graph represent the different ICF-CY codes, which were evaluated during the real-life experiences through the elaborated form. On each axis, the red dots represent the ICF-CY scores in pre-training, whereas the green dots are for post-training. Following the ICF-CY scale, the values encompass five levels from 0 (no difficulty) to 4 (complete difficulty). A dot not appearing on the axis means that there are missing values for that axis, corresponding to a score of 8 in the ICF-CY scale. The corresponding area of belonging to ICF-CY chapter for the main ICF-CY codes was reported.

training, proving to be aware of both the shopping phases and the actions to perform. Accordingly, even the coding for facilitators indicated a statistically lesser level of support from the therapists, and the VABS-II confirmed improvements in the scale of Daily Living Skills (Fig. 5) that involved items pertaining to the shopping activity. Concerning barriers, their impact was not completely identified and clearly coded for all participants. However, the results for this coding suggested that sounds were a barrier for only three participants (p3, p4, p9) and found that impact of sounds on performance was reduced after the training. Further studies, which take these variables into account, will need to be undertaken.

Since a real-life shopping session provided forms of both verbal and non-verbal communication, the assessment of shopping experiences included ICF-CY codes associated to ICF-CY Chapter 3 on Communication. Difficulties in these codes heavily compromised the participants' real-life experience during the first real-life session. After the virtual training, except for p1, p2, and p5, that did not present specific communication problems, significant differences were found in comprehending and receiving spoken messages (d310) for all participants. In this regard, improvements in this code depended strongly on the progress of other codes, since effective communication required attention, as well as understanding actions to carry out. Participants were thus more receptive to spoken messages because the SG not only stimulated their listening skills, but also helped them learn the shopping procedure and improved their attention. Results were also supported by scores of the Environment Factors component, which reported a scoring decrease for facilitators, and by statistical improvements in the VABS-II Communication scale (Fig. 5). As for the ICF-CY code d315, which showed no statistically significant changes, we observed that missing values were present both pre- and post-training, or rather, that the observers had insufficient information to assign a score to the code. Moreover, as shown in Fig. 2 and Fig. 3, some of the participants (p1, p2, p3, and p6) did not exhibit difficulties in the first shopping session, so properly assessing effects of the training on this particular skill was not possible. No statistically significant changes were registered even in the coding of the Environmental Factor

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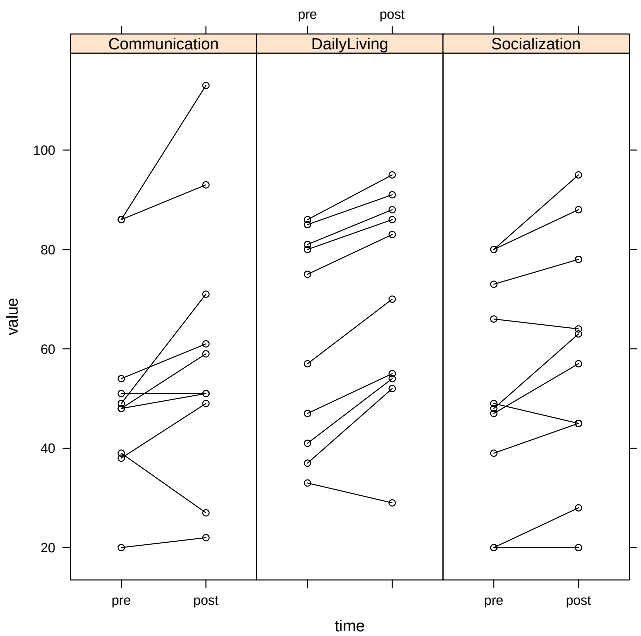

Fig. 5. Pre- and post-training values for the Vineland Adaptive Behavior Scale II (VABS-II). The figure shows the values of the VABS-II both pre-training (during the diagnostic screening of the participants) and post-training (after the second real-life experience, at six months from the first VABS-II assessment).

component for this code. Training with the game may not have affected these skills, despite *ShopAut 2.0* providing images and symbols to reinforce comprehension of nonverbal messages.

The analysis of the ICF-CY codes related to Mobility revealed statistical improvements in hand and arm using (d445) and moving around in different locations (d460). Although our SG did not provide specific motor training, it is plausible that participants' motor abilities (specifically hand and arm using) were improved after the training, since the participants that had more difficulty in this code before were more aware of the different required tasks and actions. However, for this code, we did not detect statistically significant changes in coding of Environmental Factors. Except p1 and p6, relevant statistically progress was observed on ICF-CY code d460 in all participants, as the participants were able to orientate themselves in the supermarket and walk intentionally in the environment (Fig. 2, Fig. 3 and Fig. 4). In fact, our SG was set in a real supermarket, or rather, it was developed following the real structure of the chosen supermarket. This way, participants got acquainted with the environment and its structure and organization during the game sessions. Changes in this code were also observed in the level of facilitations offered by the therapist for these actions. For the ICF-CY code d440 (fine hand use), which showed no statistically significant improvements, participants were observed to have no significant difficulty even pre-training, and the game did not provide specific training on fine motor skills required by shopping activities. This outcome may suggest that these skills should be practiced with other interventions or using other technologies in combination with the SG to implement a specific fine motor training.

Regarding social interactions, ICF-CY d730 was a hard code to evaluate in the first shopping experience because not all the participants interacted with strangers in their real-life experiences, for several reasons; specifically, pre-training scores were missing for participants p4, p5, p7, and p10 because they did not complete the experience, whereas participants p1 and p8 did not have a chance to interact with strangers. Moreover, even in the second real-life experience, p8 did not interact with strangers. For these reasons, raters had not have enough information to assess this ICF-CY code; therefore, the statistical analysis of paired data for both the ICF-CY code and related facilitators did not allow us to detect possible differences pre- and post-training. However, this ICF-CY code represents one of the main ASD deficits [1], so we recommend specific and more intensive training for these skills. In fact, in comparison to other SGs aimed to train social skills in people with ASD [14], [15], [21], *ShopAut 2.0* only partially trained social interactions, given that its main purpose was to teach the procedures of shopping activities and some specific related skills, and only the last few game levels provided direct interactions with avatars. The lack of significant progress in this area suggests that further game dynamics related to social interactions should be integrated in future works on SG development.

Similar considerations can be applied to the ICF-CY code d860 related to skills for engaging in any form of simple economic transactions. In particular, in addition to the missing values in the first session (p4, p5, p7, and p10), this training represented a first approach to payments for some of the patients. In fact, the participants' therapists reported that most of them were not aware of the value of money and of monetary dynamics at the beginning of the study. For these reasons, we did not detect statistically significant improvements in this ICF-CY code. Even though the analysis based on the VABS-II Daily Living Skills scale, which includes items linked to the use of money, showed significant progress, future works should further investigate the impact of our SG-based training on these skills and should assess how game dynamics related to economic transactions should be redesigned.

Overall, the present study offered preliminary evidence for the feasibility and the use of personalized SG in the training of daily living skills in people with ASD. As speculated, significant progress in learning shopping procedures and functionally applying specific trained skills was observed after the virtual training. In particular, significant improvements were detected in learning skills, especially critical thinking abilities (e.g., classifying, problem solving, decision making) and communication skills (e.g., listening actively, reading). Moreover, the personalized SG-based training made the real-life environment predictable, significantly empowering orientation and self-control abilities. Beyond an assessment of the real-life shopping sessions, VABS-II scores also detected important clinical improvements. Considering that the VABS-II scale was rated through a questionnaire filled in by the parents and involved items related to all possible life contexts, increases in this scale might point to the potential benefits of the virtual training to the generalization process and the maintenance of trained skills outside the gaming context.

According to previous studies [15], [19], [32], [33], *ShopAut*

2.0 incorporated all the key principles (i.e. individualization, motivating storyline, system of feedback and reward, minimalist user interface, increasing of difficulty, fun elements) that should be considered when designing a SG for people with ASD, while also integrating suggestions for personalizing the virtual SG-based training. On one hand, similarly to earlier SGs, in-built individualized features were added involving customized starting points, ASD-specific learning goals, and a threshold to access the next game levels. On the other hand, unlike other SGs, we engineered a system of facilitators based on ASD severity levels within the game, and we reproduced the same real-life environments as suggested by the ASD Guidelines. Moreover, we provided different inputs and game-perspectives to further personalize the game experience. In line with current results, future versions of *ShopAut* are expected to integrate game dynamics to further improve shopping skills, specifically practical money skills and social skills. Moreover, in order to enhance personalized game features, we intend to integrate artificial intelligence techniques into the game to dynamically adapt and personalize the experience based on the player's reactions.

Consistently with the literature [15], [20], [23]–[25], [27], this research confirms that SGs can be great motivators for people with ASD, even in the training of daily living activities that can appear boring or unnecessary [27]. All participants showed progress in their shopping skills after the virtual training, regardless of ASD severity level and intellectual abilities. This finding suggests that the personalized approach in our SG design facilitated comprehension of the game itself and its dynamics to all participants, consequently improving their outcomes. In other words, the personalization of difficulty and contents, the system of game facilitators based on the ASD severity levels, the customization of inputs, and the friendly user interface made *ShopAut 2.0* accessible to the heterogeneous group of participants. This finding is consistent with previous studies [19], [20], [32] that emphasized the importance of taking into consideration the varied spectrum of features of people with ASD for SG design, so that every individual with ASD can benefit from the training.

Despite encouraging preliminary results, the current study presented some limitations due to its exploratory nature. The small sample size limited the study generalization and analysis to differences in the range of improvements across the three ASD severity levels. Perhaps, improvements varied among participants because of their own clinical features and because the SG-based training was short. In fact, following previous studies [14], [15], [19], we considered 10 weekly training sessions with the SG to assess possible improvements, but further works are necessary also to investigate how training length can affect results. For instance, it is possible that ASD severity level 3 participants may require longer-term training to achieve improvements compared to severity level 2 or 1 patients. Additionally, the outcomes of the SG-based training were investigated in a short-term follow-up, so it is not clear whether the achieved improvements will be maintained over time. Moreover, since this was a pilot study to investigate the feasibility of a training based on personalized SGs, a control group was not included. Finally, to support ICF-CY scores and our results, future investigations should involve quantitative parameters in the assessment of the real-life shopping experiences, such as time of completion for a shopping list task, the number of interventions from therapists, and the number of correct actions performed in the real-life experiences.

V. Conclusion

This preliminary study is, to our knowledge, the first to investigate changes among individuals with ASD in the daily living activity of shopping after a training with a personalized SG. On one hand, we proposed new in-built individualisation game features and elements that could be useful to design personalised SGs for people with ASD and to provide an individualised game experience. On the other hand, we provided a new perspective to assess how virtual training with personalized SGs can impact daily living skills by carrying out real-life shopping sessions pre- and post-training and evaluating changes in VABS-II scores at 6 months from the baseline. Our findings support the potential benefits as well as the feasibility of training with personalized SGs to practice daily living skills. Moreover, this study will be of interest to prove that personalised SGs can be used effectively in rehabilitation, family, and educational routines to support people with ASD, thus providing new strategies of intervention.

Future works should additionally investigate the potential of training with personalized SGs and should involve the validation of our preliminary results through a fully powered randomized controlled clinical trial that: 1) explores how training length, ASD severity levels, and environmental factors in real-life settings related to outcomes; 2) evaluates outcomes with a longer-term follow-up to assess whether skills are maintained over time.

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