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IN

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

A PERSONALISED SERIOUS GAME TO IMPROVE DAILY LIVING SKILLS IN PEOPLE WITH AUTISM SPECTRUM DISORDER

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"Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious. And however difficult life may seem, there is always something you can do and succeed at. It matters that you don't just give up."
(Stephen Hawking)

Abstract

Autism Spectrum Disorder (ASD) includes a set of neurodevelopmental chronic disorders characterised by two main categories of symptoms: deficits in social communication and social interaction; restricted patterns of behaviours. The degree of impairment in these two domains can change radically among individuals and ASD is often associated with intellectual disability, psychiatric impairments, and other kinds of comorbidities, hence the high heterogeneity in the clinical presentation of ASD. ASD symptoms appear in early childhood but generally persist throughout life, so ASD is considered a lifelong disorder.

As shown in several studies, technology-based interventions such as serious games (SGs) represent an innovative tool to support children and adults with ASD. Serious games motivate the player and facilitate the learning of skills and the training of actions and behaviours that can then be transferred to real life. However, SGs aimed at people with ASD show several limits; in particular, SGs often fail to consider the heterogeneity of the disorder and the different functioning profiles of individuals with ASD, they present a restricted range of topics and genres, and above all, their assessment proves little evidence of skill generalisation from the virtual world to real-life contexts. These limitations do not aid the spread of serious games in rehabilitation contexts and increase the gap between research and practice.

The aim of the present thesis is to investigate new methodologies and techniques to improve autonomy in people with ASD through a personalised serious game. More specifically, a rehabilitation SG-based intervention for people with ASD was carried out for enhancing skills related to a specific daily living activity: shopping in a supermarket. The underlying hypothesis of this study is that training with an individualised serious game can improve the learning and generalisation of trained skills in a real-life environment. In order to prove this hypothesis, a sample of ten subjects with ASD, aged between 8 and 16 years, played with a personalised serious game, *ShopAut*, for ten sessions, one per week, for no more than 30 minutes. Before the training with *ShopAut*, a real-life experience was observed to evaluate the participants' performance in a real supermarket. After the training with *ShopAut*, a second real-life experience was carried out to assess the improvements achieved by the participants.

This study involved a multidisciplinary team, namely a biomedical engineer, a neuropsychiatrist, a psychologist, neuro and psychomotor therapists, speech therapists, and occupational therapists. The team planned and coordinated the rehabilitation intervention, designed the SG analyzing the personalized elements that had to be implemented in the game, and assessed and validated the effectiveness of the intervention.

The serious game *ShopAut* was developed integrating an individualised design that provides both the personalisation of the game's scenario, contents, difficulty, and user interface; and the customisation of game modes, player perspectives, and input devices. It is a three-dimensional game conceptually based on classic 3D life simulation games and provides a realistic shopping experience where the player can practice and engage with, above all, shopping activities, experiment their problem-solving skills, and take on unexpected events.

For the assessment of pre- and post-training, an ad hoc form based on the *International Classification of Functioning, Disability and Health: children and youth version* (ICF-CY) was used to evaluate the participants' functioning in the supermarket, and a clinical standardised scale, *Vineland Adaptive Behavior Scale II* (VABS-II), was adopted to measure the ability of the participants to perform daily activities. Moreover, the game performances of the participants were analysed over the game sessions.

The personalised design allowed us to individualise the game experience, improving gameplay, playability, and usability, and consequently the learning outcome. Participants found our SG enjoyable and engaging. The results from the real-life experiences show a significant improvement in the real-life performance of the participants, especially in the main skills trained with *ShopAut*. More specifically, the training helped the participants to maintain their attention on specific actions, to improve problem-solving and orientation skills, and above all to enhance their ability in the shopping activity. Improvements were also proved by positive scores on the VABS-II scales, especially in daily living skills.

Overall, the current study provides good evidence for the use of personalised SGs in interventions for children and teens with ASD. In particular, the results suggest that personalised SGs can effectively support rehabilitation interventions for people with ASD to improve generalisation process and autonomy.

The outline of the thesis is as follows:

Chapter 1: introduces the context of this research by defining the two main key terms: Autism Spectrum Disorder and serious games. In particular, ASD diagnostic criteria, recent epidemiological data, and the main kinds of intervention were summarised. Analogously, SGs were presented, showing their main application domains as well as the design and development process behind them.

Chapter 2: provides a systematic literature review on SG-based intervention for people with ASD, analysing application domains, technologies used, intervention procedures, and assessment methods.

Chapter 3: describes the methods and methodologies adopted in this research, providing information on our SG's design, the participants, the procedure of the intervention, the outcome measures and the statistical analysis.

Chapter 4: shows the results of this research, in particular, it reports the analysis of the participants' performances in the real-life experiences, the scores achieved in the clinical tests, and the game performances.

Chapter 5: discusses the results of this study examining strong points and limitations of the study. Moreover, it recapitulates the major findings of the thesis, suggesting issues that might inspire future research.

Appendix: contains the Game Design Document of our SG and a brief technical report of its development.

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1 Introduction

In this chapter, the main key concepts of the present research are introduced. As described in the abstract, the study has a focus on the use and efficacy of Serious Games as an intervention for individuals with Autism Spectrum Disorder. Thus, it is essential to introduce and define the meaning of both Autism Spectrum Disorder and Serious Games. In particular, the first section of this chapter presents the main features of Autism Spectrum Disorder, its diagnostic criteria and recommended interventions, according to the International Guidelines. The second section introduces and illustrates the potentialities and applications of Serious Games.

1.1 Autism Spectrum Disorder

The Autism Spectrum Disorder (ASD) encompasses a set of neurodevelopmental disorders clinically characterised by two main categories of symptoms: deficits in social communication and social interaction; restricted patterns of behaviours [1]. There is high heterogeneity in the ASD clinical presentation due to the variability of the intellectual ability, of the severity levels of the disorder, and of the associated psychiatric comorbidities [2]. ASD symptoms appear in early childhood and can change over the years with diverse developmental pathways [3]. However, the symptoms generally persist throughout life, so ASD is considered a lifelong disorder.

1.1.1 Brief History

The psychiatrist Eugen Bleuler coined the term autism to indicate symptoms of the most severe cases of schizophrenia. In particular, he defined autism as a disconnect from the outside world due to the coexistence of conflicting ideas in one's mind [4]. Leo Kanner later redefined the word autism using it as a label to describe a unique psychological disorder in children, namely, Autistic Disturbances of Affective Contact. Kanner provided eleven case studies of his patients, aged 2-8 years, identifying the following features: a) unknown aetiology; b) early-onset; c) maintenance of aloneness; d) need of sameness; e) lack of maternal warmth; f) obsessiveness, stereotypy, and echolalia [5]. In the same years, Hans Asperger carried out studies about a group of children that resembled Kanner's description, but presented a typical development of language and had deficits in fine motor skills and social interactions [6].

In the subsequent decades, the reference model was the psycho-dynamic model, according to which autism was the result of a hostile reality, unfit to satisfy the needs of protection and reassurance. The psycho-dynamic model influenced the first two editions of Diagnostic and Statistical Manual of Mental Disorders – the reference standard to diagnose mental and behavioral conditions – that considered autism as a type of childhood schizophrenia. However, this approach was subject to different discussions and critical evaluations over the years due to the medical evidence of organic changes, the success of neuropsychological theories, and the improvement of neurobiology. The findings of these research fields led to a search for the ASD causes inside the child, not outside. Today, the scientific community accepts the hypothesis that the Autism Spectrum Disorder is linked to an atypical mental functioning; more specifically, ASD is considered a dysfunction related to the Central Nervous System with many different genetic, epigenetic and environmental mechanisms being involved [7].

Since the first editions, taxonomies have struggled to define a unitary concept of autism because the disorder appears in heterogeneous patterns within the same individual. Currently, autism is considered as a spectrum of disorders, after Wing first used the term *Autism Spectrum Disorder* in 1988 [8].

1.1.2 Epidemiology

The wide circulation of the Diagnostic and Statistical Manual of Mental Disorders, especially since the third edition, helped to provide the first estimates of ASD prevalence. In 1987, the prevalence was 4-5 per 10,000 (= 1 case/2,000-2,500 individuals). With the publication of the DSM-IV, the prevalence rates indicated an estimate of 2-5 per 10,000 [9].

In 2000, the Centers for Disease Control and Prevention (CDC) established the Autism and Developmental Disabilities Monitoring Network to collect data and to estimate the prevalence of ASD in United States. The project was launched in eleven States and reported an average prevalence of 6.7 per 1,000. In the subsequent years, the number of involved states increased to fourteen, and according to the last epidemiological estimates, 1 out of 59 children aged 8 years is diagnosed with ASD in United States [10].

In Europe, the European Commission funded a three-year (2015-2018) programme, Autism Spectrum Disorders in Europe (ASDEU), to research autism diagnosis, prevalence and interventions and to improve care and support for people with ASD. ASDEU was the first programme to uniformly evaluate ASD prevalence in Europe, and 14 European countries were involved [11]. In the ASDEU final report, 1 out of 89 children aged 7-9 years is diagnosed with ASD in Europe [8]. In Italy, the ASDEU researchers reported a prevalence of ASD in children aged 7-9 years of about one out of 87 [12].

Furthermore, ASD can occur in all ethnic, racial and socioeconomic groups and males have been shown to be affected by ASD four times more often than females [10].

1.1.3 Taxonomies and Diagnostic Criteria

The debate over the etiological and pathological aspects of the disorder facilitated an accurate description of the behavioural profile of individuals with ASD. As a matter of fact, many researches have worked to define its diagnostic criteria independently from the causes since the 70s. This approach characterizes the two main reference taxonomic and diagnostic tools used today: the Diagnostic and Statistical Manual of Mental Disorders (DSM), published by the American Psychiatric Association [1], and the International Classification of Diseases (ICD), published by World Health Organization [13].

1.1.3.1 Diagnostic and Statistical Manual of Mental Disorders

The Diagnostic and Statistical Manual of Mental Disorders – fifth edition (DSM-V) is now the standard reference for the diagnosis of psychiatric disorders, including ASD. The DSM-V defines Autism Spectrum Disorder as a complex neurodevelopmental disorder characterised by deficits in social communication and social interaction, and by limited patterns of interests, activities and behaviours [1]. In particular, the DSM-V reports the following standard diagnostic criteria:

A Persistent deficits in social communication and social interaction across multiple contexts, as manifested by the following, currently or by history (examples are illustrative, not exhaustive, see text):

1 Deficits in social-emotional reciprocity, ranging, for example, from abnormal social approach and failure of normal back-and-forth conversation; to reduced sharing of interests, emotions, or affect; to failure to initiate or respond to social interactions.
2 Deficits in nonverbal communicative behaviors used for social interaction, ranging, for example, from poorly integrated verbal and nonverbal communication; to abnormalities in eye contact and body language or deficits in understanding and use of gestures; to a total lack of facial expressions and nonverbal communication.
3 Deficits in developing, maintaining, and understanding relationships, ranging, for example, from difficulties adjusting behavior to suit various social contexts; to difficulties in sharing imaginative play or in making friends; to absence of interest in peers.

Specify current severity: Severity is based on social communication impairments and restricted repetitive patterns of behavior (See table 1.1).

B Restricted, repetitive patterns of behavior, interests, or activities, as manifested by at least two of the following, currently or by history (examples are illustrative, not exhaustive, see text):

1 Stereotyped or repetitive motor movements, use of objects, or speech (e.g., simple motor stereotypies, lining up toys or flipping objects, echolalia, idiosyncratic phrases).
2 Insistence on sameness, inflexible adherence to routines, or ritualized patterns or verbal nonverbal behavior (e.g., extreme distress at small changes, difficulties with transitions, rigid thinking patterns, greeting rituals, need to take same route or eat food every day).
3 Highly restricted, fixated interests that are abnormal in intensity or focus (e.g, strong attachment to or preoccupation with unusual objects, excessively circumscribed or perseverative interest).
4 Hyper- or hyporeactivity to sensory input or unusual interests in sensory aspects of the environment (e.g., apparent indifference to pain/temperature, adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination with lights or movement).

Specify current severity: Severity is based on social communication impairments and restricted, repetitive patterns of behavior (See table 1.1).

C Symptoms must be present in the early developmental period (but may not become fully manifest until social demands exceed limited capacities or may be masked by learned strategies in later life).

D Symptoms cause clinically significant impairment in social, occupational, or other important areas of current functioning.

E These disturbances are not better explained by intellectual disability (intellectual developmental disorder) or global developmental delay. Intellectual disability and autism spectrum disorder frequently co-occur; to make comorbid diagnoses of autism spectrum disorder and intellectual disability, social communication should be below that expected for general developmental level.

The DSM-V criteria require to specify if:

- With or without accompanying intellectual impairment.
- With or without accompanying language impairment.
- Associated with another neurodevelopmental, mental, or behavioral disorder
- With catatonia
- Associated with a known medical or genetic condition or environmental factor

Moreover, the DSM-V identified three severity levels based on the required support, as shown in table 1.1.

Table 1.1: Severity levels of Autism Spectrum Disorder identified by DSM-V. The table reports the three severity levels of Autism Spectrum Disorder identified by DSM-V, describing their features in the main two ASD deficits.

Severity Level	**Social Communication**	**Restricted, repetitive behaviors**
Level 3 Requiring very substantial support	Severe deficits in verbal and nonverbal social communication skills cause severe impairments in functioning, very limited initiation of social interactions, and minimal response to social overtures from others. For example, a person with few words of intelligible speech who rarely initiates interaction and, when he or she does, makes unusual approaches to meet needs only and responds to only very direct social approaches	Inflexibility of behavior, extreme difficulty coping with change, or other restricted/repetitive behaviors markedly interfere with functioning in all spheres. Great distress/difficulty changing focus or action.
Level 2 Requiring substantial support	Marked deficits in verbal and nonverbal social communication skills; social impairments apparent even with supports in place; limited initiation of social interactions; and reduced or abnormal responses to social overtures from others. For example, a person who speaks simple sentences, whose interaction is limited to narrow special interests, and how has markedly odd nonverbal communication.	Inflexibility of behavior, difficulty coping with change, or other restricted/repetitive behaviors appear frequently enough to be obvious to the casual observer and interfere with functioning in a variety of contexts. Distress and/or difficulty changing focus or action.

Level 1 Requiring support	Without supports in place, deficits in social communication cause noticeable impairments. Difficulty initiating social interactions, and clear examples of atypical or unsuccessful response to social overtures of others. May appear to have decreased interest in social interactions. For example, a person who is able to speak in full sentences and engages in communication but whose to-and-fro conversation with others fails, and whose attempts to make friends are odd and typically unsuccessful	Inflexibility of behavior causes significant interference with functioning in one or more contexts. Difficulty switching between activities. Problems of organization and planning hamper independence.

1.1.3.2 International Classification of Diseases

The International Classification of Diseases–11th edition (ICD-11) defines ASD as follows: "Autism Spectrum Disorder is characterised by persistent deficits in the ability to initiate and to sustain reciprocal social interaction and social communication, and by a range of restricted, repetitive, and inflexible patterns of behaviour and interests. The onset of the disorder occurs during the developmental period, typically in early childhood, but symptoms may not become fully manifest until later, when social demands exceed limited capacities. Deficits are sufficiently severe to cause impairment in personal, family, social, educational, occupational or other important areas of functioning and are usually a pervasive feature of the individual's functioning observable in all settings, although they may vary according to social, educational, or other context. Individuals along the spectrum exhibit a full range of intellectual functioning and language abilities" [13].

ICD-11 follows the definition and description of the DSM-V with some significant differences, as there is no reference to the sensory abnormalities that characterize people with ASD. Moreover, ICD-11 distinguishes between autism with and without an intellectual disability, providing different guidelines.

1.1.4 Etiopathogenesis

The ASD aetiology remains unknown. ASD is regarded as a multifactorial disorder caused by genetic, epigenetic, and environmental factors. However, genetic factors play a prevalent role, as evidenced by several genetic studies. In particular, ASD was evaluated in homozygous and heterozygote twins: in the first case, there is a 36-95% chance of the symptoms to appear, while in the second one it is about 0-31% [14, 15, 16, 17]. Other studies detected that parents who have a son with ASD have a 2-18% chance to have a second son with ASD [18, 19]; furthermore, the ASD risk increases in the case of older parents [20] and in children born prematurely or with low birth weight [21]. ASD occurs more often in people with specific genetic or chromosomal conditions: about 10% of children with ASD has Down syndrome, fragile X syndrome, tuberous sclerosisexternal icon, or other genetic and chromosomal disorders [22, 23, 24, 25]. Environmental factors, such as immune factors, can interact with generic factors to increase the ASD risk [26].

Different studies investigated the structural and functional alterations of the Central Nervous System. In particular, alterations in brain development were shown to appear after birth. Some of the most significant anatomical data involve the growth of the brain: brain volume is normal at birth, but subsequently grows up to an extra 10% at 3-4 years of age [27].

ASD is often linked to psychiatric impairments, such as attention deficit hyperactivity disorder, depression and anxiety disorder, intellectual disability, other kinds of comorbidities - like chronic sleep problems and epilepsy [2]. In particular, the majority of patients (75%) with ASD present an intellectual disability [7, 10]; according to recent epidemiological studies, epilepsy is present in 20% of cases [28].

1.1.5 Diagnosis and Treatment

The aetiological heterogeneity of ASD determines a diagnosis based exclusively on behavioural parameters. Therefore, an accurate anamnesis, precise clinical observations, and standardised tools of assessment are essential to detect the disorder. According to the International Guidelines of Autism Spectrum Disorder [29, 30, 31, 32, 33, 34], a correct diagnosis requires a specialised multidisciplinary team and it involves both a diagnostic evaluation and a functional and support needs assessment. The diagnostic evaluation usually comprises the following main phases [7]:

1. Anamnesis, both familiar and personal.
2. General clinic examination.
3. Neurobiological examination.
4. Psychological examination.
5. Instrumental and laboratory investigations.

Moreover, the ASD International Guidelines recommend the use of standardised assessment tools for the diagnosis. The Autism Diagnostic Interview-Revised (ADI-R) [35], the Autism Diagnostic Observation Schedule (ADOS) [36], and the Childhood Autism Rating Scales (CARS) [37] are commonly used.

The functional and support needs assessment aims to evaluate the supports and resources required to assist the individual and their caregivers, providing them with appropriate support services [31].

Scientific research has shown that an early diagnosis can be considered reliable and valid [38] and that it is essential to define an effective treatment and to decrease relational and cognitive deficits [39, 40]. In fact, it is important to highlight that there is no cure for people with ASD, but a set of interventions can be implemented in order to improve the lives of people with ASD and their families.

There are many different types of evidence-based intervention available in everyday use. Despite these interventions may differ in philosophy and relative emphasis on particular strategies, they share many common elements that can be summarized in the following principles [41, 42]:

- Precocity of intervention that starts within 2-3 years.
- Intensity of intervention with the active participation of the child, for about 20-25h per week, 12 months, in psycho-educational activities evolutionarily adapted and systematically identified, with clear goals.
- Inclusion of the family in the therapeutic program.
- Inclusion of the school in the cure project of individual promoting

the relationship between the individual and the teacher/educator in single activities and in small groups activities.
- Interaction with peers of typical development.
- Documentation and evaluation of individual improvements conforming his goals.
- Environment organization such as established routines, cards for activity, minimization the distractions.
- Need to work on the generalization of the skills in new environmental contexts.
- Evaluation of the results in relation to global functioning of development, communication, social skills, cognitive skills, adaptive skills, and possible dysfunctional behaviour.

According to the SIGN Guidelines [29], the most complete guidelines on the various kinds of intervention, interventions can be grouped in non-pharmacological interventions and pharmacological interventions. The subsequent paragraphs summarize the main identified interventions so far.

1.1.5.1 Non-pharmacological interventions

Parent-mediated intervention programs are recommended for all ages in order to help the families to interact with their sons and daughters, to promote development, and to improve parental satisfaction [29].

Many individuals with ASD present problems with communication, therefore SIGN recommends *communication interventions*. In particular, these interventions can support early communication skills, parent - and clinician - led interventions (e.g. PACT [43]) and visual supports (e.g. Picture Exchange Communication System - PECS [44]), and interventions for social communication and interaction, including procedures to provide visual supports, to reduce social complex interactions, to use routine and predictable schemes, and to decrease sensorial stimulation [29].

Behavioural/psychological interventions are split in three subgroups [29]:

1. Intensive behavioural and developmental programmes based on Applied Behaviour Analysis (ABA). Different studies have evaluated their efficacy with heterogeneous results, however, showing a high variability among the individuals. Each patient should therefore be

clinically assessed to validate the efficacy of these programmes.

2. Interventions seeking to address specific behavioural difficulties, such as sleep disturbance, or to increase positive behaviours. Both have been shown to reduce the frequency and the severity of symptomatic behaviour and to aid the development of adaptive skills in individuals with ASD. Behavioural therapy for sleep disturbances is considered a good clinical practice.
3. A range of other behavioural/psychological interventions: involved therapies, such as Auditory Integration Training [45] or Facilitated Communication [46], are *not recommended*, while there is *insufficient evidence* concerning the efficacy of interventions like Music and Occupational Therapy.

As for biomedical and nutritional interventions, SIGN guidelines recommended that gastrointestinal symptoms should be managed in the same way as they would be in an individual without ASD. Furthermore, dietetic advices are indicated in individuals with ASD who display significant food selectivity and dysfunctional feeding behaviour, or who are on restricted diets that may be adversely impacting on growth, or producing physical symptoms of recognised nutritional deficiencies or intolerances [29].

1.1.5.2 Pharmacological intervention

Pharmacological interventions can relieve ASD symptoms. Neuroleptic treatments, such as haloperidol, have specifically proven to be effective on behavioural disorders [7]. SIGN guidelines take several drugs into account: sufficient evidences were found for an antipsychotic, risperidone, and a CNS stimulant, methylphenidate [29]. Risperidone is advised in case of irritability and hyperactivity in individuals with ASD for a short-term treatment (eight weeks), while methylphenidate may be considered for managing attention difficulties and hyperactivity. Melatonin may be considered for sleep disturbances if the behavioural intervention was not effective. There is insufficient evidence to advise fluoxetine; naltrexone did not show symptomatology improvements, while secretin is not recommended [29].

1.2 Serious Games

Over the last decade, serious games – also called learning games, educational games, immersive learning simulations and game-based learning – became very popular, obtaining a significant market share in the gaming industry [47]. A serious game (SG) can be defined as a simulation with a videogame structure whose purpose is to promote the development of essential skills and knowledge in the users [48]. A SG includes the common aspects of a game – such as entertainment, challenges and a realistic environment – combined with educational and training goals. Several studies showed the positive results of SG use both in training and learning [49], and they have been applied in different areas: education, military, training, and healthcare.

1.2.1 History Overview

The origin of the concept of SGs can be ascribed to Plato, who was the first to propose games as a guide to the child's development, distinguishing between those that were played for fun and those that leaned towards learning. It was only with the theories of Enlightenment philosophers Friedrich Schiller and Jean-Jacques Rousseau, however, that playing was first viewed as an activity with specific educational aims [50]. Subsequently, the development of pedagogical and psychological theories spread the idea that games played an active role in the educational and training process.

Researcher Clark Abt was the first to introduce the term serious games in 1987. He formally established the concept of SGs, highlighting the potential of games in teaching and training contexts for students of all ages and in many situations. He defined SGs as follows: "Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining" [51]. Moreover, Abt differentiated between non-digital games and digital games; however, the diffusion of SGs in a digital context mainly began only in 2000.

The commercial spread of SGs was correlated to the birth of the Serious Games Initiative (https://www.wilsoncenter.org/program/serious-games-initiative) in 2002, led by David Rejeski and Ben Sawyer in collaboration with the Woodrow Wilson International Centre for Scholars headquartered in Washington. Sawyer stressed the importance to connect the commercial video game industry with educational contexts, redefining the term serious game as: "any meaningful use of computerized game/game industry resources whose chief mission is not entertainment" [52]. 2002 is considered a milestone in the history of serious game both for the birth of the Serious Games Initiative and for the launch of the videogame America's Army (https://www.americasarmy.com/).

America's Army was financed by the U.S. government in order to promote both the image of the army and the enrollment of new soldiers. America's Army launched SGs in the military field, determining a revolution in military training. Currently, America's Army is used by the U.S. Department of Defence, the Army and Secrete Services for staff training [53]. In accordance with Sawyer's definition, Zyda – one of the creators of this videogame – offered another general definition of SGs: "A mental contest, played with a computer in accordance with specific rules, that uses entertainment, to further government or corporate training, education, health, public policy, and strategic communication objectives" [54].

1.2.2 Definition and Features of Serious Games

Serious game may sound like an oxymoron, as one term seems to reject the other. The adjective *serious*, however, merely indicates the game's purpose and the reasons behind its development, while the word *game* refers to an activity that involves and entertains the player [47].

The several definitions available for SGs may look similar, but they are actually different in certain peculiar aspects, depending on the SG's purposes and applications, as pointed out in the previous paragraph. Hence, it is not easy to give a unique definition that is universally accepted; Dörner et al. [55] provided a more general definition: "A serious game is a digital game created with the intention to entertain and to achieve at least one additional goal (e.g., learning or health). These additional goals are named characterizing goals". Bryan Bergeron, on the other hand, offered more details: "An interactive computer application, with or without a significant hardware component, which has a challenging goal; is fun to play and/or engaging; incorporates some concepts of scoring; and imparts to the user a skill, knowledge, or attitude that can be applied in the real world" [56].

Bergeron's definition is essential to introduce and define the main features of SGs, as 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 a SG is to acquire skills and knowledge; (3) the *game itself*, because SGs have the structure of actual videogames, and gameplay elements motivate and involve the player [53].

Regarding simulation, SGs can recreate real-life environments, which may prove difficult to reproduce, or virtual environments where the player can safely experiment real-life situations or conditions, therefore learning from their mistakes with no real consequences for their actions [57].

SGs facilitate various processes of learning, particularly *situated learning*, because they represent interactive experiences where the player can train skills in specific contexts (*learning by doing*). Moreover, SGs are based on *simulation learning* because they promote the learning of procedural knowledge, or rather the knowledge that follows the rule: "if x, then y". In addition, SGs enable players to develop and train skills, knowledge or attitudes that can be then transferred in real-life contexts. The player can accurately observe a scene and its objects, evaluating the chronological succession of actions to do (*learning by reflexion*). These observations facilitate visual and motor memory, which aids the generalization of skills and knowledge for subsequent applications, even in the absence of a simulation model [58]. The learning process in a SG is a designed experience [59] because it is planned, organized, and built around a specific instructional design that is elaborated by different experts [60]. Consequently, the game tasks and their difficulties progressively increase on the basis of the instructional design [61]. *Stealth learning* is another aspect to consider in the learning process: the player can unconsciously learn skills or knowledge throughout the several game sessions; in fact, SGs are usually based on the logic of problem solving, which includes reasoning training, critical thought, and knowledge networks.

SGs share several elements with traditional videogames both in philosophical terms (game philosophy) and game design. As to game design, main common features are:

- *Storyline*: the story of the game that involves the player in a fully immersive experience, since the player is part of the story. The storyline is the heart of the game and is essential to motivate the player to play. It can be supported by dialogues, videos, and animations and can employ several characters besides the main character embodied by the player, characters who can enrich the game by adding missions, obstacles, challenges, sometimes even mystery. All game dynamics are linked to the storyline.

- *Game mechanics*: the rules of the game, both implicit and explicit. Game mechanics entail the rules the player follows and the rules the game itself follows. The combination of different mechanics determines interactions, complexity level and difficulty of the game. Examples of game mechanics are the rotation systems of the game objects or the scoring systems.
- *Game dynamics*: these are patterns that define how both the game and the players will evolve over time and are tailored to the game mechanics. Examples of game dynamics are competition, cooperation, multiplayer and single player.
- *Scenario*: the game environment where the game actions take place.

However, videogames represent a hobby for the players and do not have a learning purpose; this is what sets them apart from SGs, whose main purpose is learning via entertaining. Entertainment is simply the tool used to motivate the player and hold their attention [53].

The learning experience is the main focus of a SG, therefore an assessment of the player is pivotal to determine its efficacy. SGs need to evaluate the player's performance and their learning improvements through a specific feedback system. The assessment has to take into account the particular genre or application field of the SG, so either generic models are adapted to the respective field or domain-specific models are used [55].

1.2.3 Taxonomies and Application Domains of Serious Games

Serious games are applied in various domains – such as healthcare, education, business, military or politics – so different taxonomies have been suggested according to several criteria. Sawyer and Smith [62] were the first to propose a taxonomy for SGs based on a matrix of two major criteria: market (the application domain) and purpose (initial purpose of the designer), as shown in figure 1.1. This taxonomy kicked off a series of different classifications regarding SGs, especially in the subsequent years.

Mautone et al. [63] defined a taxonomy based on five salient elements: feedback and scoring; rules and constraints; challenge; structure and instructional support; fantasy. Bente and Breuer [64] proposed a flexible classification in order to promote the production and to describe and compare SGs among researchers; this taxonomy is based on nine criteria:

1. Platform (e.g., PC, mobile phone, Wii).
2. Subject matter (e.g., latent semantic analysis, cooking fish).
3. Learning goals (e.g., be able to compute if 2 documents are close using LSA, know 20 kinds of sea fish).
4. Learning principles (e.g. rote memorization, exploration, observational learning, trial and error, conditioning).
5. Target audience.
6. Interaction mode(s) (e.g., multiplayer, Co-Tutoring, single player, massively multiplayer, tutoring agents).
7. Application area (e.g., academic education, private use, professional training).
8. Controls/Interfaces (e.g., gamepad controlled, mouse and keyboard, Wii balance board).
9. Common gaming labels (e.g., puzzle, action, role-play, simulation, card game, quiz).

Researchers at the University of Toulose created the website http://www.serious.gameclassification.com, providing a taxonomy based on the following multiple criteria: gameplay, purpose, market and target audience, and user-contributed keywords. This taxonomy, which groups videogames (including SGs) in a global category with various sub-categories, is currently the reference classification.

The reported taxonomies include global classifications, but there are also specific taxonomies based on precise application domains, especially in the health field [65, 66, 67].

SGs combine concepts, principles, methodologies, technologies, and information with game elements to achieve a desired learning goal. For this reason, the application domains are very different: training and simulation, digital educational games ranging from kindergarten to university, vocational or workplace training, marketing and advertisement games, health games for prevention and rehabilitation, or social awareness and impact games covering societal relevant topic such as politics, security,

	Games for Health	Advergames	Games for Training	Games for Education	Games for Science and Research	Production	Games as Work
Government & NGO	Public Health Education & Mass Casualty Response	Political Games	Employee Training	Inform Public	Data Collection / Planning	Strategic & Policy Planning	Public Diplomacy, Opinion Research
Defense	Rehabilitation & Wellness	Recruitment & Propaganda	Soldier/Support Training	School House Education	Wargames / planning	War planning & weapons research	Command & Control
Healthcare	Cybertherapy / Exergaming	Public Health Policy & Social Awareness Campaigns	Training Games for Health Professionals	Games for Patient Education and Disease Management	Visualization & Epidemiology	Biotech manufacturing & design	Public Health Response Planning & Logistics
Marketing & Communications	Advertising Treatment	Advertising, marketing with games, product placement	Product Use	Product Information	Opinion Research	Machinima	Opinion Research
Education	Inform about diseases/risks	Social Issue Games	Train teachers / Train workforce skills	Learning	Computer Science & Recruitment	P2P Learning Constructivism Documentary?	Teaching Distance Learning
Corporate	Employee Health Information & Wellness	Customer Education & Awareness	Employee Training	Continuing Education & Certification	Advertising / visualization	Strategic Planning	Command & Control
Industry	Occupational Safety	Sales & Recruitment	Employee Training	Workforce Education	Process Optimization Simulation	Nano/Bio-tech Design	Command & Control

Figure 1.1: Serious games taxonomy. The figure shows the taxonomy for serious games proposed by Sawyer and Smith [62].

religion, energy, or climate [55]. The main application domains of serious games are reported in the following paragraphs with related examples.

1.2.3.1 Training Serious Games

Training is a common and important field for SGs, for both economic reasons and the wide array of application scenarios it can offer. Examples in this domain include training programs for military forces, such as *America's Army*, *SanTrain* [68], *Decisive Action*, and *Harpoon 3* [47]. The success of SGs in military training is relevant because soldiers can experiment war situations and conditions safely, improving their ability to differentiate targets, multitask, and work in a team with minimum communication [69].

Other application fields are service staff training (e.g., bus, drivers, pilots, and flight attendants), civil relief organizations, and corporate training. In particular, corporate training represents a large market for the SGs industry because, according to [69], SGs change both the role of the trainee from passive to active and the role of the trainer from just delivering material to being a facilitator. In addition, SGs help to develop collaborative, communication, strategy, job-specific, and organisation skills; SGs examples are *VIPOL* (https://www.tricat.net/public-solutions/?lang=en), *Pacific* (shorturl.at/hiFQ9), or *ADA* (shorturl.at/gqHR7).

1.2.3.2 Educational Serious Games

The Summit on Educational Games [70] identifies the following features of educational SGs:

- Clear learning goals: you know why you are learning something and there are opportunities to apply what you learn.
- Broad experiences and practice opportunities that continue to challenge the learner and reinforce expertise.
- Continuous monitoring of progress, and use of this information to diagnose performance and adjust instruction to learner level of mastery.
- Encouragement of inquiry and questions, and response with answers that are appropriate to the learner and context.
- Contextual bridging: games and simulations can close the gap between what is learned and its use.

Educational SGs appear to have similar purposes to training SGs but they differ in target users and contents. In addition, educational SGs are used at school or as supplementary learning material. Examples for serious games in education are: *Techforce* (https://www.spielbar.de/node/145269, *Civilization* (www.civilization.com), *The Elder Scrolls: Oblivion* (www.elderscrolls.com/oblivion), or *Roma Nova* [55].

However, it is essential to consider the recommendation suggested by [70] on SGs use for this application, which is a controversial issue. There are few outcome reports for using educational games, a lack of information that discourages educators and teachers from trying them. In addition, as reported by [47, 69], there are also other questions concerning the educational environment (especially school) that need to be answered, such as resources (many schools have computers that are too old for newer games; technical support; the time required for teachers to familiarise with the game) or how to identify the relevance of a game to statutory curricula.

1.2.3.3 Health Serious Games

SGs have become an innovative tool used both for training and for assessment in the healthcare domain. Following the classification proposed by [65], SGs for healthcare can be classified based on the player type in:

- *Patient*: SGs developed for patients with different purposes, such as health monitoring, detection, treatment, rehabilitation, and education for self/directed care.
- *Non-Patient*: SGs developed for health and wellness – which focus more on exercise, enough sleep, maintaining a healthy body weight, limiting alcohol use, and avoiding smoking – and training and simulation for both professional and non-professional use.

As for games for professional training, they can support either the development of technical and non-technical skills or education and they are addressed to all healthcare professionals. The player can value their skills in different environments such as clinic, surgery or the emergency room, but they can also take on rare clinical cases or try difficult medical procedures [66]. In addition, the learner can test their skills and knowledge in a learning environment without real consequences on the patient's life.

SGs for patients can support the patient in different pathways such as distraction therapeutic tools, tools of diagnosis and treatment of mental illness/mental conditions, tools for rehabilitation. There are many examples of SGs in the health domain; for a complete list, see [47, 65, 55, 69].

1.2.4 Design and Development of Serious Games

The design of serious games requires a balance between technology, educational content and game elements. The excess of one these factors can generate a non-positive experience; for example, an overload of learning contents can produce a boring game, while an excessive focus on the playful aspects can undermine the learning purpose.

As reported in [71, 72, 73], there are various frameworks and tools that can be used to design a serious game; however, the literature shares that the design has to involve videogame specialists such as game designers, programmers or graphic designers, as well as other professional figures that have no connection with the technical development but are experts both in the application domain and in the target users of the serious game, as shown in figure 1.2. The different figures have to work together from the first conceptual stages of the SG until its release.

The design process starts with forming an idea of the characterizing

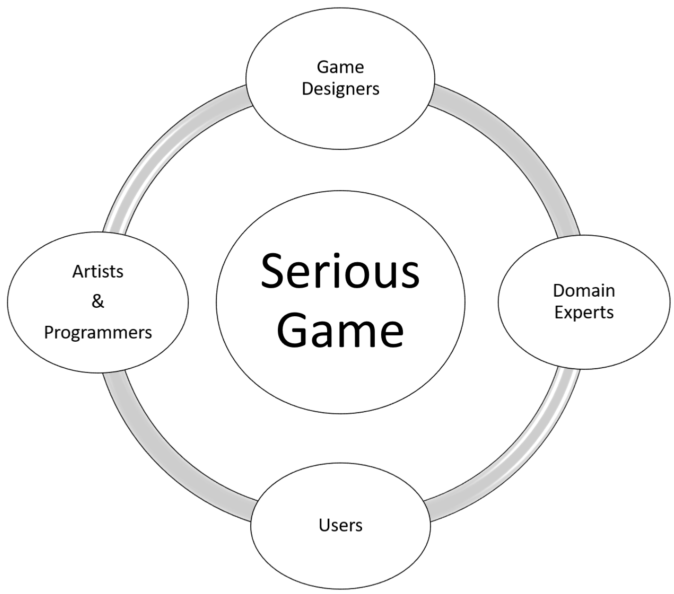

Figure 1.2: Human resources involved in SG design process. The figure shows the different human resources involved in the design process of serious games.

goals and the application scenario. These are the core parts of a serious game so it is essential to define them clearly. The main answer to which the team has to respond is: "How can this serious game improve the player's outcomes?" To answer this question, it is essential to define a specific target group; the player's age, sex, and other features play a large role in the design and development of the game [55]. For these reasons, the SG team has to carry out a background analysis, interviewing a small user group to understand possible problems and attractive elements they could introduce in the game, as well as studying literature and projects of interest [74].

The definition of the goals and users represents the starting point to the creative process behind the game concept. In traditional videogames, this phase usually involves only the game designers, but the entire team, especially game designers and experts, is involved in SGs. The challenge of the creative process lies in the integration of the characterizing goal with the game contents. A well-designed serious game has to include game elements that entertain the player, but also requires said player to develop skills, to resolve problems, to plan, and to understand what to do [69].

The design team usually draws up a Game Design Document (GDD) that describes the game features; it is a common document in videogame development process, but its structure depends on the genre of the game [75]. Salazar et al. [76] provided a general structure for a GDD, which is organized in the following sections:

- *Overview*: a summary of the game concept including the game goals and history.
- *Game mechanics*: a section that describes all elements of the game, such as characters or assets list.
- *Game dynamics*: a section that describes the interactions of the game elements like interfaces, levels or artificial intelligence.
- *Game aesthetics*: what the player perceives by his senses has two main aspects, the visual and the auditory.
- *Game experience*: a section that explores relevant issues for the game design and the expected quality of the game while the player plays.
- *Assumptions and constraints*: a section that illustrates the technical and business constraints.

Therefore, the GDD collects all ideas, materials, and elements so that the concept and features of the game can be shared with all the involved parties in order to facilitate the development phase.

The development phase consists in the development of the design plans and in the implementation of game prototypes, which should be tested by users. As in videogame development, the development of a serious game follows an iterative cycle in which the game is improved over time. The iterative approaches have established themselves as best practice: designs are revised several times and the game is developed step by step. Dörner et al. proposed a basic scheme of this process, as reported in figure 1.3: the evaluation phase, especially the user testing process, is extremely important. In particular, user usability, playability, and gameplay have to be evaluated in order to establish whether the development is complete or a new iteration needs to be started [77, 78]. However, the development quality of a serious game heavily depends on the processes chosen to coordinate and to support all authors involved.

Software engineering offers various methodologies to facilitate the management of the production process. One of the most adopted methodologies is *scrum*: an agile framework used to manage the software development with the goal of delivering new software capability in a short time [79]. Scrum can promote the communication and the cooperation between the different team members, but also helps controlling implementation [80]. In addition to methodologies, technologies – including software and hardware – play an essential role in the development process. The market offers different game engines to develop a videogame: Unity [81] and Unreal Engine [82] are the most common among developers.

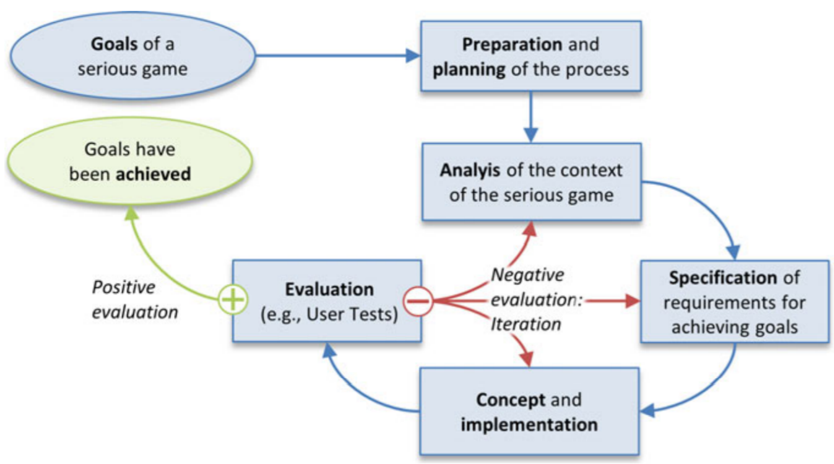

Figure 1.3: The phases of an iterative cycle in the development of serious games. The figure shows the flow and phases of iterative approaches to develop serious games.

2 Literature Review

This chapter illustrates an extensive literature survey to analyse the state-of-the-art of serious games applications in Autism Spectrum Disorder. More specifically, a brief introduction on the technology and its use in interventions and treatments for people with ASD is presented. Subsequently, the role of serious games is illustrated, providing a systematic overview on their application in the ASD sector. Several studies have evaluated serious games use as a tool to support traditional therapy for people with ASD in order to improve communication, learning, social behaviour and, in different ways, motor abilities. In this review, the studies are grouped based by SG purpose and the main researches with validated results are presented. Studies that focused only on SG design or usability results were excluded.

2.1 Technology and Autism Spectrum Disorder

The technological development has been providing new opportunities for helping people with ASD by supporting skill learning, communication, and autonomy [83, 84]. Assistive and prompting devices, computers, video modelling, virtual and augmented reality, robotics, computer-play are only some of the many possible technologies used to enhance the quality of life for people with ASD and their families. The spread of technology in this context is due mainly to its universal availability. Technological devices – such as tablets, computers, smartphones – are very popular, user-friendly, and affordable. Moreover, technology offers different benefits to people with ASD [85], with respect to their core deficits:

- it grants different input devices: technological devices are flexible, portable, and more accessible;
- it gives priority to the visual channel: people with ASD are often visual thinkers, so they prefer pictures both for learning and for elaborating information;
- it can reduce the steps required to complete a task or give a visual representation of the task steps in sequence in order to help users to learn and understand the progression of complex actions;
- it responds to the specific needs arisen by the atypical sensory profile:

according to DSM-V [1], people with ASD show high sensitivity, therefore technology allows them to control sensory stimuli (e.g., sound regulation);

- it motivates users: people with ASD show a natural affinity with technology due to its predictable and structured environment without direct interactions;
- it supports communication: technology provides several devices and software that can improve communication, especially in the case of nonverbal individuals with ASD.

Technology use can have different purposes based on the specific needs of the individual; in particular, it can be used for playful, educational, rehabilitation, communication, and training goals. The ASD International Guidelines [30, 34] report positive results for technology-based interventions on emotion recognition and social skills training. Moreover, technology supports the educational practices for students with ASD: on the one hand, it is a useful tool for teachers to prepare, adapt and update materials; on the other hand, it supports the learning process with individualised applications and strategies [86].

Following the taxonomy proposed by Aresti-Bartolome and Garcia-Zapirain [87], the technology applications for people with ASD can be classified in four categories: (a) virtual reality applications; (b) dedicated applications; (c) telehealth systems; (d) robots.

Over the last few years, researchers have investigated the use of virtual reality applications, in social intervention for people with ASD. More specifically, virtual environments offer safe, realistic, learning scenarios where to train and experiment everyday situations [88]. Moreover, virtual reality provides a promising framework to facilitate individualized treatment and to actively involve the user [89].

As for the dedicated applications with communication purposes, an application of great interest supporting people with ASD is the Augmentative and Alternative Communication (AAC) [85]. AAC is defined as "an integrated group of components, including symbols, aids, strategies and techniques used by individuals to enhance communication" [90]. AAC is useful for any child with Autism Spectrum Disorder who is unable to use speech to meet their communication needs [91]. Aided AAC systems – the AAC systems mainly recommended for individuals with ASD – require the use of adaptive equipment and tools, both lowtech (e.g., communication boards or books) and high-tech (e.g., mobile devices or speech generating devices) [85]. For the last case in particular, different apps have been developed for all mobile devices to support AAC application, such as Proloquo2Go (https://www.assistiveware.com/) or Let me Talk (https://www.letmetalk.info/it).

Telehealth systems are dedicated applications used to support families of people with ASD, offering healthcare services [87]. They can facilitate the diagnosis, early intervention, information sharing with parents on treatments, intervention monitoring, and rehabilitation [88].

An innovative area of research is represented by social robotics. Robots respond to specific needs of people with ASD due to their predictable behavior and controlled interactions [87]. In particular, previous research has investigated the different roles that robots can assume: a friendly playmate, a social mediator or actor, a personal therapist, a diagnostic agent [92]. Different kinds of robots – both humanoid and non-humanoid robots – with different kinds of movements (e.g., whether they can move their arms or legs or are mobile) equipped with a variety of tools such as cameras, microphones and speakers are used in this research field.

However, it should be noted that despite the existence of substantial research on technology use for people with ASD, technology-based interventions are still considered new approaches and their clinical validity is still a matter of debate [93]. In fact, the literature tends to emphasize the potential of technology more than it is focused on proving the actual effects it produces. In addition, as reported in [87], there also several limitations to technology use in intervention for people with ASD, as summarised in the following points:

- The content needs to fit the ages of individuals with ASD and limits should be set for the use of these technologies. While they can help people with ASD to practice strengths and improve on their weaknesses, they can also create addiction and lead to further isolation.
- Mixed reality, robots and dedicated applications provide predictable interactions which allow users to feel secure and comfortable, but do not reflect the variables that exist in real life. More research is needed to establish if skills can be transferred and thus improve the users' quality of life.
- The tools are developed for the entire autism spectrum, failing

to consider the different severity levels of people with ASD, their cognitive functions or language evolution and their needs. It would be interesting to develop configurable systems that could be adapted to each person, thus achieving more efficient tools.

- Research available consists of pilot studies with a small number of participants who are mostly children, and follow-up studies have not been conducted to check whether the participants have maintained the improvements achieved during the tests, or in other words, whether the participants have been able to transfer the results achieved to their daily lives.

In conclusion, technology is a tool that can support people with ASD in different ways but, as with most things, balance is key and is essential to promote individualised designs in the development of technologies for people with ASD, to provide guidelines for its use, and to validate its effectiveness.

2.2 Serious Games and Autism Spectrum Disorder

The applications of serious games are various and have different purposes in the ASD field. Over the last few decades, there has been an increase in publications that opened new scenarios for the diagnosis and the treatment of people with ASD. In this paragraph, the state-of-the-art in SGs that have already been developed is explored, providing a SG classification based on their main purposes. In particular, for each SG category, a brief report was included for the more relevant papers and a summary table of papers involved was provided.

This research has been performed through the following databases: PubMed (US National Library of Medicine, http://ncbi.nlm.nih.gov/pubmed), Scopus (Elsevier, http://scopus.com), Web of Science (Thomson Reuters, http://apps.webofknowledge.com), and Google Scholar (http://scholar.google.it). The selection was limited to articles appearing in the English language published between 1 January 2010 and 31 December 2019. The search query included clinical terms (Autism Spectrum Disorder OR ASD OR Autism OR Autistic OR ASC (Autism Spectrum Condition)) AND technological terms (Serious Game OR Computer game OR Educational game OR Game-based intervention OR Digital game

OR Videogame OR Virtual game).

The result for each search was manually screened to remove duplicates, misclassified papers, and out of scope papers. The first level of screening was conducted by abstract; subsequently, the selected papers were assessed for eligibility. In particular, the following inclusion criteria were used: studies that (a) involved only serious games developed or adapted for people with ASD with all type of technological devices, (b) included a group of participants formally diagnosed with ASD, and (c) assessed intervention or indicated assessment measures in the case of a preliminary study. Studies that investigated only the SG development, usability or satisfaction were not considered; reviews were also excluded. For studies that had more publications on the same SG, the more detailed paper about SG was selected; while, for studies that used the same SG but with different analysis were included.

45 papers were selected through the review process and were organized in four domains based on the purposes of SGs: diagnosis; education intervention; training; and rehabilitation intervention (Figure 2.1). Figure 2.2 reports the number of papers per year and shows an increment of studies during the years.

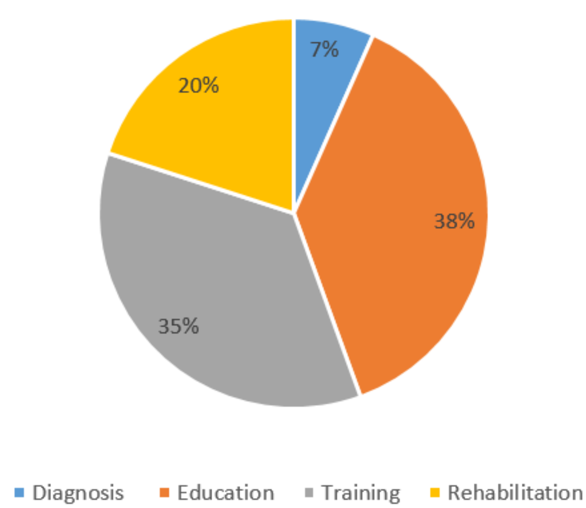

Figure 2.1: Pie-chart of selected papers based on the purposes identified in the review process. The image shows the distribution of the analysed papers with respect to the purposes identified in the review process.

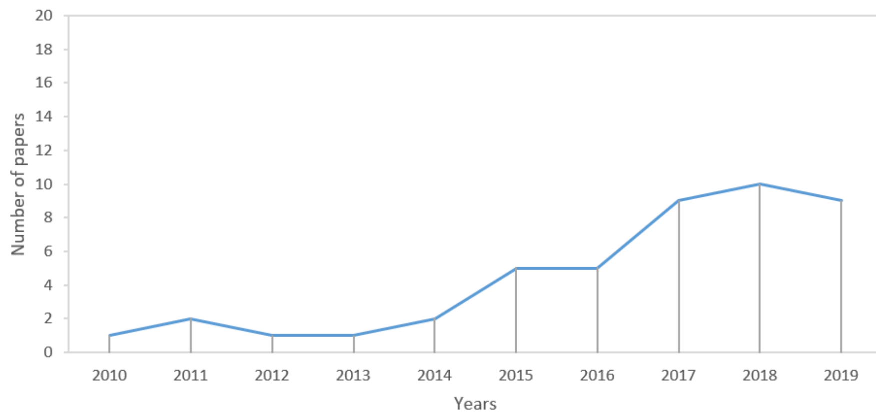

Figure 2.2: Number of selected studies in the review process per year. The figure shows the number of papers selected in the review process from 2010 to 2019. It highlights how the number of studies increased over the years, which shows the interest of the scientific community and research progresses in this field.

In the subsequent paragraphs, the main results of the review are presented; in particular, a summary table reporting the main features of the selected studies was provided for each domain.

2.2.1 Serious Games for Diagnosis

Serious games for diagnosis were developed to improve and facilitate ASD diagnosis, especially in early age. In particular, the literature identified motor disturbance as a new parameter for the early detection of ASD in young children [94, 95], opening new lines of research on serious games for people with ASD. Anzulewicz et al. [96] adapted *Play.Care*, which is a commercial serious game and iPad mini application developed by Harimata SP ZOO, in order to determine the kinds of movements responsible for differentiating between children with ASD and children with typical development. The game was formed by two levels: "Sharing", where the player had to tap a piece of food to split it into four pieces; and "Creativity", where the player had to trace the outline of a drawing and then colour it. All information pertaining motor actions was detected through touchscreen and inertial sensors (tri-axial accelerometer, gyroscope, magnetometer). From machine learning data analysis, they identified movement patterns determining whether or not a particular child's gameplay fit a diagnostic classification. *Play.Care* was used in another study, which was conducted by Millar et al. [97] in order to validate the predictive value of the serious game for ASD diagnosis. However, their results are not available yet because data are currently being collected.

Other serious games have been developed to support the diagnosis process, or rather, to distinguish between children with and without ASD, following other indicators. In particular, Irani et al. [98] proposed a SG, *EmoGalaxy*, for an ASD screening based on emotion detection, expression and regulation. The game is set in four planets that represent the main emotions (happiness, sadness, fear, and anger). *EmoGalaxy* was developed both for Android and iPhone. The authors showed that the results had a high level of accuracy. Chen et al. [99] proposed a set of customised games with the aim to assess joint attention and gaze following and to test the player's ability to understand and have social interactions. Even in this case, the results suggested that the game was useful to support the assessment process, as children with ASD present difficulties in joint attention, fine motor skills and cognitive understanding.

Table 2.1: Details of the studies with a diagnostic purpose included in the review. The table shows the papers with a diagnostic purpose selected for this review, summarising in detail the main features of both SG technology and SG-based intervention.

Authors	**SG Technology**		**SG-based Intervention**			
	Platform	**Graphic**	**Players**	**Intensity**	**Setting**	**Assessment**
Anzulewicz et al. (2016) [96]	tablet (iPad mini) with inertial sensor	2D	N=37 (25 males and 12 females); 4 years	x1 session; 7 min.	clinical setting	analysis of motor actions
Irani et al. (2018) [98]	tablet (Android and iPad)	2D	N=23 (males)	-	research setting	game score and classification algorithm
Chen et al. (2019) [99]	PC	2D	N=40	x1 session; 15-20 min.	clinical setting	game score

2.2.2 Serious Games for Education

Serious games developed to improve the learning process have the goal of helping children or teachers during the acquisition of skills and knowledge. In particular, some papers [100, 101] evaluated the word learning, such as the the one proposed by Khowaja and Salim [102]. In this study, the authors proposed a framework to design SGs for children with ASD and investigated the effectiveness of a SG prototype. The game was developed as a mobile application to help children with ASD learning new words. The experimental results showed good improvements in the vocabulary of the participants.

Some serious games [103, 104, 105] were developed to support the learning of specific contents. For example, the game proposed by Bossavit and Parsons [105] aims to help players learn geography-specific knowledge and integrates several strategic features so that users can collaborate together against the computer or compete against each other. This game was developed with and for young people with ASD. The results proved that there had been considerable benefits both in the involvement of the participants and in their geography knowledge.

Bernardini et al. [106] have developed *ECHOES*, a SG that improves learning and communication in children with ASD using an avatar. The avatar represents a learning tutor for the player, interacting with them and providing different learning activities. These activities focus on social communication and, in particular, on the two sub-components of social communication (joint attention and symbol use). *ECHOES* was one of the first studies carried out in a real school context, and preliminary results demonstrated that *ECHOES* may be beneficial to the learning process and the communication of children with ASD.

Other articles evaluated the SGs use to improve the reading process [104, 107], as learning to read can be a real challenge for children with ASD. For instance, *SEMA-TIC* is a serious game for children with ASD developed by Serret et al. [107] to teach them the prerequisites for reading. *SEMA-TIC* is a computer application and the player can play using the mouse. The game provides ten series of ten games each to teach literacy skills and the game difficulty progressively increases. The authors investigated the adaptability, efficiency, and effectiveness of the game, and validated the results with reading tests. The results suggested a positive impact, especially on minimally verbal school-aged children with ASD.

People with ASD often have difficulties in recognising, understanding and expressing their emotions, therefore several studies [108, 109, 110, 111, 112] investigated the learning and the improvement of affective skills in children with ASD through serious games. One of the first developed applications for emotion recognition is *Let's Face it!* [113], a computer-based intervention formed by seven interactive games targeting various face processing skills. To investigate the effectiveness of the program, a randomized controlled clinical trial was designed. The results showed improvements in children with ASD on analytic recognition and holistic recognition of faces. On a similar note, Serret et al. [114] developed *JeStiMulE*, a virtual reality game addressed specifically to children and adolescents with ASD with the aim to train their emotion recognition skills, including facial expressions, emotional gestures, and social situations. The authors noticed the positive effects of the serious games but stressed the need for further studies on the generalization of trained skills in order to completely validate SGs. Meanwhile, Fridenson-Hayo et al. [115] conducted a cross-cultural evaluation of *Emotiplay*, which is a serious game aimed at teaching emotion recognition (https://emotiplay.com/). The game was developed as an internet platform and was designed for children with ASD, especially high-functioning individuals. The storyline involves the player in a research on human behavior and emotional expression. The study proved that *Emotiplay* can be considered a valuable tool to facilitate and support emotion recognition. Recently, Petrovska and Trajkovski [116] evaluated a computer-based intervention on emotion understanding in 17 children with ASD. The intervention was provided via *Ucime Emocii*, a cross-platform web application designed for children with ASD, and was split into two parts: test module and game module. The game module provides opportunities for learning and practicing emotion recognition through six interactive games. The results are in line with the previous studies, and positive effects were observed especially in emotion recognition applied to photographs of real faces and pictograms, as well as situation-based emotions.

Table 2.2: Details of the studies for educational intervention included in the review. The table shows the papers selected for this review, summarising in detail the main features of both SG technology and SG-based intervention.

Authors	**SG Technology**		**SG-based Intervention**			
	Platform	**Graphic**	**Players**	**Intensity**	**Setting**	**Assessment**
Cunha et. al. (2012) [100]	PC	2D	N=3	x10 sessions	research setting	pre- and post-test
Pistoljevic and Hulusic (2017) [101]	Web platform	2D	N=10 (9 males and 1 females); 4-7 years	x5 sessions	school	specific questionnaire
Khowaja and Salim (2019) [102]	PC	2D	N=5 (males); 6-10 years	x34 sessions; 20 minutes	research setting	game accuracy and classification algorithm
Kamaruzaman et al. (2016) [103]	Web platform	2D	N=15 (13 males and 2 females); 7 years	x16 weeks	school	Involvement Scale and game time
Yakkundi et al. (2017) [104]	tablet (iPad)	2D	N=3 (males); 6-11 years	20-30 min. per session	school and home	HER reading skills and DIBELS literacy skills
Bossavit and Parsons (2018) [105]	PC with Kinect	2D	N=6 with high functioning; 9-15 years	x5 sessions; 30 min.	school	Scenario Experience Feedback Questionnaire (SEFQ), Intrinsic Motivation Inventory (IMI), specific questionnaire (for geography contents), game score
Bernardini et al. (2014) [106]	PC	2D	N=29 (28 males and 1 females); 8 years	x6 weeks; 15 min.	school	frequency of actions
Serret et al. (2017) [107]	PC	3D	N=12 (11 males and 1 females); 8 years	x23 week	clinical setting and home	questionnaire for adaptability, the Alouette Reading Test, ODEDYS test

Alves et al. (2013) [108]	table (iPad)	3D	N=11 (10 males and 1females); 5-15 years	15 min.	research setting	analysis of game videos and specific questionnaire
Schuller et al. (2015) [109]	Web platform	2D	N=12 (9 males and 3 females); 5-10 years	x73 day	clinical setting	Vineland, specific survey, body gestures analysis
Azevedo et al. (2018) [110]	Web platform with micro controller and buttons	2D	N=5; 6-10 years	x4 sessions	school	game accuracy and game time
Piana et al. (2019) [111]	Web platform with Kinect	2D	N=10 with high functioning; 8-11 years	x10 sessions	research setting	TEC test
Hughes et al. (2016) [112]	tablet	2D	N=10; 7-12 years	x12 sessions; 20 min.	school	game accuracy
Tanaka et al. (2010) [113]	PC	2D	N= 42 (34 males and 8 females); 10 years	x19 weeks	home	Let's Face It! Skills Battery
Serret et al. (2014) [114]	PC with joystick	3D	N=33 (31 males and 2 females); 6-17 years	x4 weeks; 60 min.	research setting	Session × Task × Emotion interaction
Fridenson-Hay (2017) [115]	PC	2D	N=15 with high functioning (11 males and 4 females); 6-9 years	x8 weeks; 120 min.	home	SRS-2 and VABS-II Socialization scale for parents and the body and integrative ER tasks for children.
Petrovska and Trajkovski (2019) [116]	PC, tablet	2D	N=17 (13 males and 4 females); 7-15 years	8 weeks; 15-30 min.	school	ECT total, Face task, Picto task, Situation task

2.2.3 Serious Games for Training

Serious games for training involve different aspects and contents in order to improve the autonomy of people with ASD. In particular, some serious games have been developed to improve autonomy and everyday skills of people with ASD.

Scherf et al. [117] developed a serious game to train individuals with ASD to discover that the eyes, and shifts in gaze specifically, provide information about the external world. The game is a 3D adventure game developed as a computer application in which participants have to solve mysteries; the game training is focused on directional reference, reference to a specific object identity and joint attention. However, this research is a preliminary study and does not provide complete results concerning the effectiveness of the intervention.

Simões et al. [118] developed and validated a serious game to help young adults with ASD to learn how to take the bus. The game was developed as a virtual reality application and is connected to a biofeedback system that measures anxiety levels. The player can exercise on how to take a bus, and their game performance is assessed based on their correct actions during the game sessions. The ten participants were administered an intervention of three game sessions; after each game session a debriefing was carried out, and the participant's performances were compared with a control group. The results showed improvements in the theoretical knowledge of the process and a decrease in the anxiety felt by the participants. Similarly, *Take a Shower!* is a serious game developed by Kang and Chang [119] to promote personal autonomy for children with ASD. More specifically, the game is a training resource to learn to take a shower; it was developed as a computer application and is controlled by player via Kinect. The results of this training were positive and encourage SG use in shower training for children with ASD. Instead, Caria et al. [120] proposed a 2D serious game developed as a web-based game application to help people with high-functioning ASD to manage money. The game requires the player to recognise, sum and exchange money. Preliminary results were encouraging, but highlighted the need to redesign the application's graphics and sounds. Hassan et al. [121] also developed a serious game to train money identification and understanding of money value. The game was developed as a computer application and is set in a supermarket where the player has to buy some products. However, even in this case, the authors provided only preliminary results on the SG's efficacy.

Other serious games aimed at training players to foster positive behavioural skills and social skills [122, 123, 124, 125]. *FaceSay* (http://www.facesay.com/) is serious game focused on improving social interactions in children with ASD. In particular, the game is designed to teach children to attend to eye gaze and respond to joint attention. It was developed as a computer application and is one of the first developed applications for game-based educational intervention, which explains its simple interface and design. However, its effectiveness was validated by different studies [126, 127]. Uzuegbunam et al. [128] proposed *MEBook*, which is a Windows application equipped with Kinect, to improve social skills related to greeting behaviour in children with ASD. The game is made up of two sections: the first is an animated short story that describes greeting behavior, while the second offers a game to practice it. Preliminary results show that *MEBook* is effective in teaching greeting behavior to children with ASD. A similar research was conducted by Malinverni et al. [129] that developed *Pico's Adventures*, a serious game meant to promote social interactions in children with high-functioning ASD. A Kinect game, it provides both single player and multiplayer. It is set in a fantasy world where the player has to help Pico, the main character, in his adventure. The authors stressed the importance of a multidisciplinary team to design the serious game and the results showed significant improvements in the social initiation behaviors of the participants. *JOINME* is a serious game developed by Reyes et al. [130] that strives to improve interpersonal relationships. *JOINME* was implemented on a desktop PC, but the player can control the game via Kinect. It is addressed to children with high-functioning ASD and provides different modules. The results were gathered through a specific survey and showed progress in emotion recognition and good behavior. Zhao et al. [131] developed a virtual game system to train social interactions. In particular, the platform allows two player to play simultaneously an interactive mini-games. Each player interacting with this system is equipped with one Leap Motion controller, a set of headset and webcam, and one Tobii EyeX tracker. The results proved that there had been positive effects on the cooperation between the players and the verbal interactions of children with ASD during the game sessions.

Finally, Mercado et al. [132] developed *FarmerKeeper*, a serious game for neurofeedback training that could be useful to improve attention in children with ASD. While they only investigated the efficacy of the game prototype, positive preliminary results encourage the development of the game and their research.

Table 2.3: Details of the studies for training included in the review. The table shows the papers with a training purpose selected for this review, summarising in detail the main features of both SG technology and SG-based intervention.

Authors	**SG Technology**		**SG-based Intervention**			
	Platform	**Graphic**	**Players**	**Intensity**	**Setting**	**Assessment**
Scherf et al. (2018) [117]	PC with system of eye tracking	3D	N=34; 10-18 years	2 months; 90 min. per week	home	Visual attention to faces, Eye gaze sensitivity, Social Skills Improvement System (SSIS)
Simões et al. (2018) [118]	PC with Oculus and EDA sensor	3D	N=10; (4 males and 6 females); 18 years	3 sessions; 20-40 min.	research setting	game accuracy, accuracy task of debriefing, anxiety frequency and game time
Kang and Chang (2019) [119]	PC with Kinect	2D	N=6 (4 males and 2 females); 9-11 years	x21 sessions	school	accuracy actions in real-life setting pre- and post-intervention
Caria et al. (2018) [120]	Web Platform	2D	N=6; 16-22 years	2 sessions	research setting	SUS test, Task success, time, n. errors
Hassan et al. (2011) [121]	PC	2D	N=6; 9-14 years	x5 weeks	school	game performance
Barajas et al. (2017) [122]	PC	3D	N=9 (males); 6-15 years	x2 day; 15 min.	research setting	social interaction during the game performance
Sharma et al. (2016) [123]	PC with Kinect	2D	N=10 (6 males and 4 females)	11 sessions	school	game accuracy

Wang et al. (2018) [124]	PC	3D	N=11; 11-14 years	x4 monts; 2 sessions per week; 45 min.	school	video analysis
Silva-Calpa et al. (2018) [125]	tablet	2D	N=7; 5-14 years	x3 months	therapy room	social interaction expressions during the game
Hopkins et al. (2011) [126]	PC	2D	N=13; 6-10 years	x12 sessions; 10-25 min.	school	Emotion test, Social Skills Rating System (SSRS), Benton Facial Recognition Test
Rice et al. (2015) [127]	PC	2D	N=16 with high functioning; 7 years	x10 sessions; 25 min.	school	NEPSY-II Affect Recognition, NEPSY-II Theory of Mind, Social Responsiveness Scale
Uzuegbunam et al. (2015) [128]	PC with Kinect	2D	N=3; 7-12 years	x12 sessions	therapy room	analysis of motor gestures, eye contact, waving
Maliverni et al. (2017) [129]	PC with Kinect	3D	N=10 with high functioning; 4-6 years	x4 sessions; 30 min.	clinical setting	Observational analysis of behaviors with a specific checklist
Reyes et al. (2019) [130]	PC with Kinect	2D	N=10 with high functioning; 5-8 years	x1 month	therapy room	KidsLife Scale
Zhao et al. (2018) [131]	PC with Leap Motion Controller	3D	N=12; 12 years	x6 sessions	research setting	accuracy of the eye gaze detection, rate of RPCs (Remote Procedure calls), performance game

Mercado et al. (2019) [132]	PC with BCI and system 3D of eye tracking	N=20; 4-11 years	x4 sessions	therapy room	Game Experience Questionnaire, System Usability Scale, User Experience Questionnaire, FunSorter, attention indicators based on game time

2.2.4 Serious Games for Rehabilitation

Different studies analysed SG use in the treatment of specific symptoms of ASD in clinical settings and to improve interventions at home and at rehabilitation sessions.

Aresti-Bartolame and Garcia-Zapirain [133] investigated their efficacy at improving interactions between children with ASD and their therapists. Their SG consists of three difficulty levels, which depend on the type of interaction required. Moreover, the game was designed to be customised on the player's needs, providing different options. The results showed positive effects and encourage the use of SGs in a rehabilitation intervention. In this same field, Caro et al. [134] proposed a serious game to support physical therapy for children with ASD. The results indicated improvements in attention and decrements in aimless limb movements.

Moreover, some SGs such as *GOLIAH* [135] support rehabilitation interventions in children with ASD among different life contexts. *GOLIAH* is a gaming platform that aims to improve imitation and joint attention. The games require two devices (either a tablet or a PC): one for the therapist/parent (depending on the application scenario), and the other for the child designated as the player. The games can also be categorized as (a) stand-alone operation games and (b) games requiring active cooperation between the therapist and the child. All the games have varying difficulty levels, allowing the therapist/parent to adjust the initial level of difficulty according to the cognitive skills identified by the therapist at the beginning of the treatment process or to dynamically adjust it as the player's performance progresses over time. The authors reported positive results, especially on the use of the platform to monitor the treatment, while clinical positive effects were proved by Jouen et al. [136].

Wijnhoven et al. [137] have been studying the efficacy of the serious game *MindLight* in reducing anxiety in children with ASD. *MindLight* (https://gemhlab.com/games/mindlight/ is a commercial 3D game developed by the GainPlay Studio corporate that uses the mind as a game controller. In particular, as said by the developers: "*MindLight* incorporates several evidence-based strategies including relaxation and mindfulness techniques, attention bias modification methods, and neurofeedback mechanics that together produce an immersive game world through which children learn to manage and overcome anxiety symptoms". The game is addressed to children of 8-16 years and provided a first-person view through the eyes of its main character, Little Arthur. During the game, EEG signals are collected, especially Alpha and Beta waves. While the authors have provided metrics and outcome measurements, they have yet to release the results. Carlier et al. [138] also proposed a serious game, *New Horizon*, to reduce anxiety and stress in children with ASD. The game is a a 2D mobile Android exploration game and it consists of several mini games. The player is involved in a journey around the galaxy with the main character, Jimmy, as he takes on different challenges. The authors discussed positive preliminary results on a small group of participants and they will investigate the SG's actual effectiveness on a larger group.

People with ASD often have difficulties in communicating with others through both verbal and non-verbal language. For these reasons, some serious games [139, 140] have been developed. An example is the game developed by Nawahdah and Ihmouda [140], a SG that tries to help children with ASD to overcome their social and communication problems. The game, which was based on on PECS intervention, was structured in different levels, each with a specific storyline. However, the authors provided only primary results that showed a potential use of the game.

Many people with ASD present problems in sensory processing, such as hypersensitivity or hyposensitivity to sights, sounds, smells, tastes, touch, balance and body awareness. Zakari el al. [141] proposed a SG called *Sinbad and the Magic Cure* to support moderate sensory hypersensitivity in children with ASD. The game was developed as an Android application and its design was inspired by the Arabic tale.

Preliminary results suggested that the game may provide a suitable supportive tool, but future research should investigate the use of the serious game with larger groups for longer periods of time.

Table 2.4: Details of the studies with a rehabilitation purpose included in the review. The table shows the papers with a rehabilitation purpose selected for this review, summarising in detail the main features of both SG technology and SG-based intervention.

Authors	**SG Technology**		**SG-based Intervention**			
	Platform	**Graphic**	**Players**	**Intensity**	**Setting**	**Assessment**
Aresti-Bartolame and Garcia-Zapirain (2015) [133]	tablet with eye tracking	2D	N=20; 3-8 years	x3 sessions	therapy room	response time, action accuracy and Eye Tracker analysis
Caro et al. (2017) [134]	PC with Kinect	2D	N=7; 7-10 years	x12 sessions; 30 min.	therapy room	game time
Bono et al. (2016) [135]	Web platform	2D	N=14; 5-8 years	x3 months; x5 sessions per week; 30 min.	home	Number of errors, task time, game score, and questionnaire for parent's experience and view
Jouen et al. (2017) [136]	Web platform	2D	N=14 (males); 7 years	x5 sessions per weeks, 30-min	home and clinical setting	Autism Diagnosis Observation Schedule (ADOS), Vineland Adaptive Behavior Scale II (VABS-II), Wechsler scales, Child Behavior Checklist (CBCL), The Social Communication Questionnaire (SCQ), Parenting Stress Index (PSI), game score and time

Wijnhoven et al. (2015) [137]	PC with Mindwave	3D	N=60; 8-16 years	x6 sessions; 60 min.	clinical setting	EEG signals that are measured will be filtered on Delta, Theta, Alpha and Beta waves, Spence Children's Anxiety Scale and Child Depression Inventory 2
Carlier et al. (2019) [138]	tablet (Android)	2D	N=3; 6-10 years	x2 weeks	home	Spence's Children Anxiety Scale
Zhang et al. (2018) [139]	PC	2D	N=7 (6 males and 1 females); 13 years	x11 sessions; 60 min.	research setting	Game performance
Nawahdah et al. (2019) [140]	tablet	2D	N=4	-	school	Assessment of language skill parameters and response time
Zakari et al. (2017) [141]	tablet	2D	N=7; 8-11 years	x7 sessions; 25-30 min.	research setting	Audio Interactive Questionnaire

2.2.5 Review Discussion

Tables 2.1, 2.2, 2.3, and 2.4 summarise the main features and parameters – where specified – of the studies involved in this review. In particular, they report information on both SG technology and SG-based intervention.

Different technologies have been used in serious games for people with ASD, such as PCs and mobile devices combined with different input devices like Kinect. More specifically, 59% of serious games were designed explicitly for PC platforms and 24% for tablet platforms, while 17% were developed to be hosted in the Web and therefore are available on both PCs and mobile devices (that is, tablets and smartphones). Some studies [105, 111, 119, 128, 129, 134] involved Kinect as an input device both to facilitate the interaction between the player and the game and to investigate the motor actions of the participants. Other specific input devices were used in [110, 117, 132, 131], while only [142] used virtual reality applications. Moreover, the majority of SGs (76%) were developed with a 2D graphic and only 24% provide a three-dimensional environment that the player can explore.

Independently from the purpose of the SG, the number of the participants is usually small (mean sample size of participants is about 15), except for [96, 99, 106, 113, 114, 117, 137], while the age range is between 6-14 years on average. Interestingly, the majority of the studies with a high number of participants concern education. Some studies [128, 138, 141] indicated their small sample size as a limit to validate and generalize their conclusions. Participants with high functioning autism were covered in six studies [105, 111, 115, 127, 129, 130], but not all studies provided a full profile of the participants based on diagnostic criteria. The majority of the participants were males, although the sex is not always specified.

As shown in Figure 2.1, the main purposes of SG-based intervention are educational interventions and training. More specifically, two primary themes were identified: improving emotion recognition and improving social skills.

With reference to SG-based intervention sessions, a high heterogeneity can be observed, with some studies not specifying either the number of game sessions, as in [99, 104, 108, 140], or the duration of each game session. The setting is variable (research setting, therapy room, home, clinical setting, and school), but in all studies a quiet room was chosen and the participants were assisted by researchers, therapists or parents as appropriate.

Assessment methods and tools may vary and depend on the purpose and application of each SG. However, the assessment methods can be classified into five categories: (1) in-game evaluation; (2) pre- and post-testing using specific scales, depending on the application domain; (3) observations; (4) interviews (or specific questionnaires); (5) motor actions. Figure 2.3 shows the distributions of the assessment methods in the selected studies. The most common method of assessment is to consider game parameters such as game score, game accuracy or tasks, and game time. However, since these parameters are often insufficient to evaluate the actual effects of the intervention, several studies use a pre- and post-testing model. In particular, [105, 107, 109, 126, 131, 136] used in combination (1) and (2). However, it is essential to consider possible difficulties when using scales that require a direct answer from the participants with ASD, such as Intrinsic Motivation Inventory (IMI) used by [105]. Overall, the

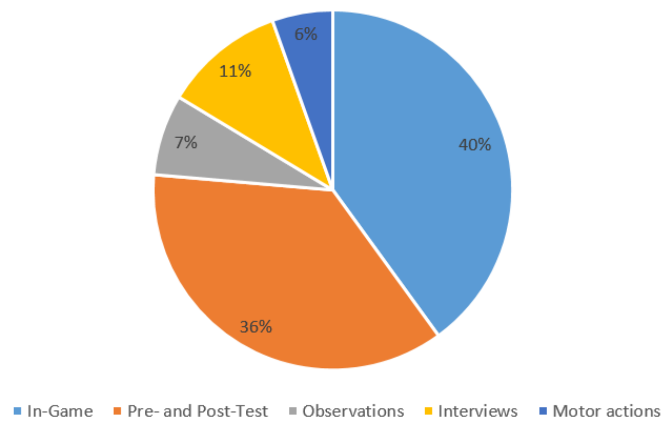

Figure 2.3: Pie-chart of assessment methods used by selected studies to evaluate SG-based interventions for people with ASD. The figure shows the distributions of the assessment methods used by the studies selected for this review to evaluate SG-based intervention for people with ASD.

assessment of a SG-based intervention highly depends on the intervention goal: for instance, in the case of SGs aimed at improving specific everyday living skills, evaluation is complex due to the absence of specific tests or *ad hoc* scales. [119, 120, 121, 142] proposed an assessment based on action accuracy, but only [119] assessed the percentage of steps performed independently by the participants after the SG-based intervention in a real-life context. However, generalization of learned skills – that is, the ability of an individual to demonstrate a behavior outside the treatment environment – is a crucial aspect of all SG-based interventions.

The review also investigated the personalisation factor of the proposed SGs. In particular, all SGs were developed or adapted for people with ASD, but only 18% offered the player the possibility to customise certain game options. Moreover, only two studies [136, 138] emphasized the necessity to adapt the gaming experience to the child's individual preferences and skills. Despite recommendations from different frameworks and design guidelines [143, 144, 145] for the development of SGs aimed at people with ASD, the potential of personalisation is still unexplored in SG-based interventions.

Overall, SGs can be used in different ways and settings to support people with ASD. However, the limits reported by [87] for technology usage for people with ASD apply to SGs as well. Therefore, it is essential to promote a multidisciplinary approach in order to develop more methodologically robust studies (e.g., defining features of the sample and treatment periods, using standardised tools of assessment); to design SGs that provide a personalised experience, for both gaming and learning; and to measure the efficacy of SG-based intervention on the generalization of skills, or rather, to assess the transfer of knowledge from the computer to real-life settings.

3 Methodology

This chapter presents the methodological and technical details of this thesis; in particular, it provides the research rationale and information related to the methods that were followed in undertaking this research as well as a discussion regarding the use of these methods. Moreover, the chapter describes the various stages of the research, which include the SG design, the selection of participants, the data collection process and the process of data analysis.

3.1 Research Rationale

According to the World Report on Disability [146], rehabilitation is "a set of measures that assist individuals who experience, or are likely to experience, disability to achieve and maintain optimal functioning in interaction with their environments". Moreover, following [146], the term *rehabilitation* includes both *rehabilitation* – measures addressed to people that lost functions in order to help them regain these functions – and *habilitation* – measures addressed to people whose disabilities are either congenital or originated early in life to help them develop the maximum level of functioning. In the same document, the term *rehabilitation* covers both types of intervention.

From these definitions, it appears clear that rehabilitation interventions aim to achieve the best level of life for an individual with a disability. In the case of ASD, rehabilitation interventions take on a particular role because they are the cornerstones of ASD treatment. As shown in the first chapter, ASD – such as other neurodevelopmental disabilities – is generally not "curable", and requires chronic management through rehabilitation and educational programmes [42]. Therefore, full rehabilitation – which includes measures directed at minimizing core features and associated deficits of the disorder and achieving independence, social inclusion, and participation – is not an option for people with ASD. In addition, due to the heterogeneity and complexity of the disorder, the ASD International Guidelines [29, 30, 31, 32, 33, 34] recommend highly individualised programmes based on both the needs of the individual and their developmental phase. Thus, interventions have to be not only personalised on the features of the individuals with ASD, but also adaptive, as they need to change over time according to advancements, treatment responses, and the developmental phase. In this respect, the NICE Guidelines [30] report: "The needs of people with autism are varied, with some people needing complex levels of support from a range of professionals and some people not wanting or needing any ongoing support. A personalised plan that is informed by the full diagnostic assessment and the individual needs of the person with autism, and recognises their strengths, should ensure that the support provided is coordinated and focused on the person's needs and the best possible outcomes for them. The personalised plan will need to be updated and reviewed as the person's needs and circumstances change. It will also need to take into account, inform and be consistent with any other plans or care packages they may have, including Education, Health and Care plans for children and Community Care Assessments for adults". Consequently, the rehabilitation plan for an individual with ASD is a complex project that necessarily requires a coordinated multidisciplinary team.

Overall, each type of rehabilitation intervention for people with ASD, including SG-based interventions, must be individualised and coherent with the rehabilitation plan of the individual. However, as shown in the previous chapter and as inferred by other reviews [143, 144, 145, 147, 148], research on interventions for people with ASD trough SGs shows severe limits in this and other aspects, such as the restricted range of topics and genres for SGs, the frequent use of non-standardised tools for outcome assessments, few multidisciplinary approaches in SG design, and above all little evidence of skills being generalised from the virtual world of SGs to real-life contexts. These limitations have been increasing the gap between technological research and clinical-rehabilitation practice.

Based on these considerations, the present research set out to study and assess the efficacy of a rehabilitation intervention for people with ASD through an individualised serious game. Moreover, this research investigated: how to design an individualised serious game for people with ASD and integrate it in a rehabilitation routine; and how to create standardised tools to describe the functioning of an individual in real-life contexts.

In order to fulfil the research aims, a multidisciplinary team was established: a biomedical engineer, a neuropsychiatrist, a clinical psychologist, neuro and psychomotor therapists, speech therapists and occupational therapists were chosen. This multidisciplinary team was essential to plan a rehabilitation intervention, to design and develop a

SG for people with ASD, to analyse the personalised elements of the game, and to assess and validate the effectiveness of the intervention. As previously mentioned, a multidisciplinary approach is required in the rehabilitation of an individual with ASD because different domains are involved in this process. On the other hand, when designing a serious game for health purposes an integrative team is generally needed to implement an efficient game [55, 149, 150, 151].

A crucial phase of the research consisted of choosing the specific domain for the rehabilitation intervention, or rather, of identifying the problems and needs where action was required in order to plan, coordinate, and carry out an effective intervention. For these reasons, a background analysis dedicated to the study of literature and projects of interest was conducted and different questions, both clinical and rehabilitation, were raised during this process. In particular, ASD severity is scientifically proven to significantly affect the quality of life of people with ASD and their families. While a small percentage of people with ASD become independent in adult age, these do not usually exhibit intellectual disabilities nor physical or psychological impairments and they live in positive environments [152, 153]. Therefore, the majority of adults with ASD require a different level of support over time that is mainly provided by their parents or caregivers due to a severe lack of both services and careful preparations for the future [152, 153, 154, 155]. Consequently, families are often under a great deal of stress — emotional, financial, and sometimes even physical [156, 157, 158]. For these reasons, improving autonomy is one of the most fundamental goals in a rehabilitation programme of an individual with ASD. In particular, the term *autonomy* involves both social – that is, the ability to make independent choices, to interact with others, to be an active part of society – and personal autonomy - intended as the ability to manage oneself independently and to satisfy one's own needs.

Learning daily living skills is essential for people with ASD to significantly promote and improve an independent life among the different contexts of life [159, 160]. These skills are connected to the personal and social sphere and include self-care, self-control, and self-regulation, as well as time and money management, transportation, and the respect of social norms [161]. Therefore, difficulties in daily living skills and activities can negatively impact the participation of individuals with ASD to the social life, generating distrust in themselves and determining necessary assistance by parents o caregivers [162]. While these skills may appear easy to learn and practice, they are actually quite complex and composite for people with ASD because they involve different abilities and knowledge simultaneously; for instance, cooking a meal is an articulate activity that involves good time management (e.g., respecting cooking times), making decisions (e.g., choosing ingredients), understanding each task separately (e.g., understanding the different recipe directions), recognising sources of dangers (e.g., fire or cutting tools). Hence why acquiring daily living skills requires a specific training for people with ASD [163]; this training can be carried out via technological tools, which include serious games. In fact, serious games facilitate the learning of procedural knowledge and the process of *learning by doing*. However, few serious games [118, 119, 142, 164] developed for people with ASD focus on daily living skills, and only [118, 119] evaluated the impact of the intervention.

Daily living skills and activities were identified as the intervention domains of this research; in particular, shopping in a supermarket was selected as the characterizing goal. Shopping in a supermarket, just as cooking a meal, is a procedural activity that involves different skills and knowledge, such as: categorization and recognition of products (e.g., identifying the products to buy); orientation skills (e.g., orientating among the different aisles); self-regulation and self-control (e.g., engaging and maintaining a socially correct behaviour); knowing the sequence of shopping activities (e.g., going at the cash register to end the shopping); decision making (e.g., choosing a specific product among various similar products); problem-solving (e.g., when the desired product is not available); engaging in any form of economic transaction (e.g., paying to the cash register); managing unforeseen events (e.g., a stranger asking for help); and social skills (e.g., respect of social conventions). Moreover, supermarkets are a loud environment with bright lights and a variety of smells that can create problems in people with ASD due to their difficulties in sensorial processing [1]. In this respect, the National Autistic Society released a short video showing how some people with ASD feel in a shopping centre (the video can be viewed here https://www.youtube.com/watch?v=aPknwW8mPAM). Several supermarkets in the UK (https://www.bbc.com/news/uk-44884183) and New Zealand (https://bit.ly/36qSipx) have even launched the "quiet hour" project, which reduces lighting, radio transmissions and announcements in order to make the shopping easier for people with ASD.

Each shopping session requires the individual to have a shopping list, or rather, to know what to buy; therefore, three main tasks were selected for the present research: (1) picking up the ingredients for a dish (pasta with tomato sauce); (2) picking up personal care products; (3) picking up a product for a party. These tasks were chosen randomly, but they are all related to daily living skills (especially task 1 and 2) and social skills (3).

Rehabilitation interventions aimed at improving autonomy are part of the planning for the transition to adult life [165] and they need timely planning for people with ASD, especially in early adolescence, if not even earlier [166]. Therefore, people with ASD aged 8-16 years were chosen for this research. Moreover, a specific experimental protocol was developed identifying three main phases:

1. *Pre-intervention*: first real-life experience to evaluate the participants' performance in a real supermarket.
2. *Intervention*: virtual training with the individualised serious game to train, experiment, and practice behaviours and actions.
3. *Post-intervention*: second real-life experience to evaluate the improvements achieved by the participants after the training.

3.2 Design of the Serious Game *ShopAut*

SG design, as shown in the first chapter, is a complex process, independently of the target audience; and different frameworks have been developed to support it [73], even for SGs targeted at people with ASD [83, 102, 143, 144, 148, 167, 168]. Following these frameworks, our research team identified the subsequent key points:

- *Personalisation and customisation*: this element was object of careful consideration and involved several aspects of the SG, especially contents, inputs, scenario and game dynamics.
- *Evolving tasks*: increasing the difficulty over the game levels. Through this feature, players stay motivated and challenged.
- *Instructions*: providing instructions to the player via tutorial levels, videos or visual cues.
- *Feedback*: planning and providing a feedback system to inform the player on the validity of their actions, especially whether they were correct or incorrect.

- *Storyline*: creating a narrative background to support the gameplay experience and to motivate the player.
- *Graphic Interface*: developing simple and clear graphics with a clear font.
- *Repetition*: providing the possibility of repetition in order to facilitate the learning process.

Periodic team meetings were scheduled during the design and development phases to review each step, solve problems, and make decisions for the following stages in an iterative process. Moreover, a Game Design Document (GDD) was drawn out identifying the main features of the serious game, such as a description, the game scenarios, the game dynamics, the feedback system and the software to be used. Appendix A1 reports the full GDD of the Serious Game, while the development phase are illustrated in Appendix A2. In the following section, a game overview of the serious game and an analysis on its personalisation were provided.

3.2.1 Game Overview

Our serious game, *ShopAut*, is a three-dimensional game that was conceptually inspired by classic 3D life simulation games. It was developed as a computer application and provides two input devices: a joystick controller and a keyboard with a mouse. The game provides a realistic shopping experience where the player can specifically practice and engage with several kinds of shopping activities, as well as experiment their problem-solving skills, take on unexpected events, and interact with others. In particular, the game aims to teach 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 consists of ten levels of increasing difficulty, the first one being a tutorial level meant to introduce the player to the game. Before launching the game, the main menu allows the player to select the game level, their own ASD severity level, and the type of player (i.e., third- and first-person view). In particular, the option for the ASD severity level provides different facilitators – such as images or directions – in the game. After setting up the different game options, each game level starts by introducing the main character, Nello, who asks the player to help him buy certain products. If a third-person view was previously chosen, the player controls Nello directly. The game takes place in the supermarket chosen for the real-life experience and includes two environments: the supermarket and its parking lot. The player can move into these two scenarios and they can interact with all the objects that can be useful for shopping. The shopping game experience is interactive and the player can select the products through a fictional barcode scanner positioned on the shopping cart. The game score is calculated based on the accuracy of the game actions, and the player can be awarded a gold, a silver or a bronze medal at the end of each game level. The player has access to the subsequent level from the main menu only if they have earned a medal; otherwise, they have to play the same level again in order to advance. A feedback system is present in the game in the form of sounds and textual messages based on the accuracy of the player's actions. When the player makes a mistake, they can repeat the action to understand where they went wrong.

The game was developed using Unity as a game engine and runs on Windows 10 Home 64-bit, 32 GB RAM and Intel Core i7 7th Generation.

3.2.2 Personalised Design

Until now, the personalisation of the interventions for people with ASD was discussed as an essential element to satisfy their various features and needs. On the other hand, literature reviews – both the one provided in the second chapter and other scientific reviews [143, 144, 145, 147] – have shown how this aspect was only partially involved in the design and development of SG-based intervention for people with ASD. More specifically, there are different approaches, aspects, and implementations that can create confusion between researchers and developers. In fact, the literature sometimes talks about *personalisation*, and other times about *customisation*, but there are differences that should be noted when using these terms. Dörner et al. [55] defines personalisation as: "In the context of games, often the term personalisation is used for a (static) one-time adaptation of a gaming aspect to the needs or preferences of a user". Moreover, the *personalisation* of serious games, as inferred by Streicher and Smeddinck [169], concerns the learning contents and aims to provide a personalised experience in order to improve engagement and information processing in the player. In the case of *customisation*, the player chooses and regulates their own game experience, for instance when a player creates an avatar based on their preferences [169]. Overall, despite personalisation and customisation being often used interchangeably, there is a subtle difference that had to be evaluated.

In view of these considerations, *ShopAut* was developed integrating an individualised design that provides both the personalisation of the game's scenario, contents, difficulty, and user interface; and the customisation of the game mode, player perspective and input devices. The game's setting reproduces the real structure of the supermarket where the participants were involved in the real-life experiences pre- and post-intervention. This way, the participants got acquainted with the environment and its structure and organization during the game sessions. The choice to recreate the real-life environment is in line with one of the recommendations for the interventions for people with ASD: organizing and making the environment predictable [32, 33].

ShopAut's learning contents were developed on real-life shopping activities and possible real-life situations. Each step was identified in order to build the game structure and storyline (as shown in Fig. 3.1). The difficulty of serious contents increases with the progression of the game levels. In fact, according to [143], "Serious games cannot be so difficult that they frustrate and/or discourage individuals from attempting to complete the game, nor so easy that the player never learns new skills". Therefore, the first *ShopAut* levels allow the player to understand the game and its dynamics. As the player becomes more expert, new challenges are introduced in order to maintain engagement and motivation, and other contents are integrated in order to improve different skills. The challenges for each level are reported in Table 3.1; level 1 is excluded because it is a tutorial level. The description of each game level is reported in Appendix A1.

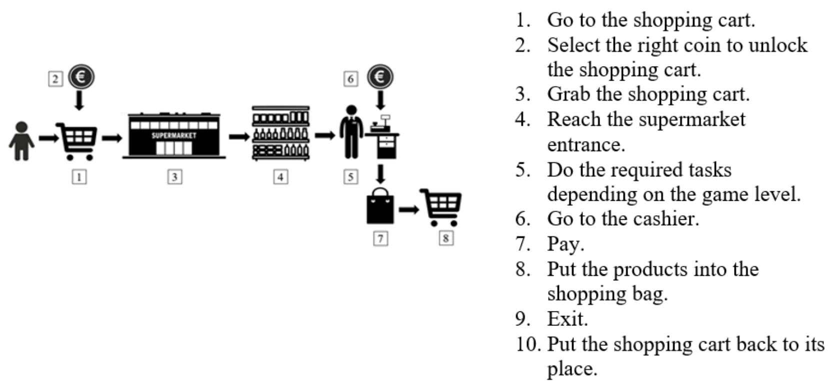

Figure 3.1: Checklist with all the different steps in a shopping experience. The figure shows the main progressive steps that make up a shopping experience.

Table 3.1: Difficulty of the game levels in the serious game *ShopAut*. The table summarises the several difficulties that are progressively integrated in the serious game *ShopAut*. The number of tasks in the shopping list increases every three levels.

Game Levels	**Game Difficulty**
2-4	The shopping list provides only one item based on the main three tasks. The player is tasked with buying a specific product (e.g., specific colour or brand) or a specific number of products.
5-7	The shopping list provides only two items based on the main three tasks. Simple economic transactions are required. Real-life sounds are reproduced in the game, including noise (e.g., music, traffic noise). Unexpected elements are introduced (e.g., aisles being locked due to works).
8-10	The shopping list provides the three tasks and the player can choose among all available products without specific directions. The economic transactions required are more complex. Interactions with avatars are introduced. A timer limit is introduced.

In order to individualise the game experience, depending on the ASD severity level of the player three different game modes can be selected through the main menu (as shown in Fig. 3.2). These game modes were delineated by analysing the three different severity levels defined in DSM-V (Table 1.1). The different modes provide different facilitators to the player based on the game levels. For instance, game mode 3 (which is addressed to ASD severity Level 3) provides the player with facilitators such as directions, guided routes, images and symbols, and visual and sound feedback to draw the player's attention.

The last element involved in the personalisation of our serious game is the user interface (UI). As highlighted in different studies [143, 148], it is essential to develop an easy and friendly UI in serious games aimed at people with ASD. In fact, intricate user interfaces can confuse the player and influence the immersion level. Therefore, a user interface with a simple design was developed to guarantee a friendly game experience. More specifically, *ShopAut*'s UI shows game missions, instructions, textual feedback and possible visual facilitators.

In addition to personalisation, our individualised approach in the design of *ShopAut* enabled the customisation of game inputs and options. In addition to accessible learning contents, input devices need to be easily accessible in SGs, and even more so in SGs targeted at people with ASD [121, 128]. Approximately 90 % of traditional videogames are controlled by a keyboard and mouse, joysticks and gamepads. However, technological improvements have been providing new input devices to entertain and engage the players, such as Nintendo's Wii Remote or Microsoft's Kinect, and new sensors such as finger sensor Leap Motion or body movement sensor Virtuix Omni for VR applications. Unlike traditional videogames, serious games require different inputs depending on their application domain, purpose and, above all, their target audience [55]. For instance, when developing a SG for children aged 3-5 years, easier technologies such as a touch screen are recommended, as this is what is more commonly used by this target audience. In SGs targeted at people with ASD, selecting a technological device involves other considerations: atypicalities in motor skills [170] (e.g., atypicalities in bimanual coordination or eye-hand coordination) and atypical sensorial processing [1]. Therefore, players should be let free to customise the input devices in order to improve their game experience. For these reasons, our serious game was developed to provide different input options: either a joystick controller or a keyboard with a mouse. In addition, the player can choose between a first- or a third-person perspective and can regulate the game audio via the game menu; this way, the player can customise their game experience according to their specific needs (as shown in Fig. 3.2).

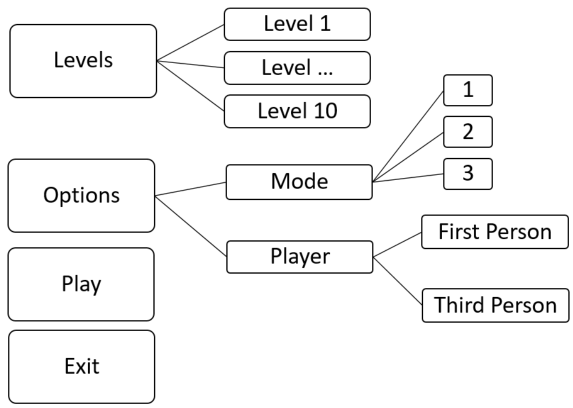

Figure 3.2: Structure of the main menu of the Serious Game *ShopAut*. The figure illustrates the structure of the main menu developed for the serious game *ShopAut*.

3.3 Participants

Ten children and teenagers with ASD (8 males and 2 females) were recruited for this study. In particular, subjects were recruited from the patients diagnosed with ASD at the Department of Translational Medical Sciences - University of Naples Federico II - following a rehabilitation programme at the medical centre Centro Medico Riabilitativo Pompei (Strada Statale 145, 64, 80045 Pompei NA, https://centropompei.webnode.it/). This medical centre is specialised in the rehabilitation of people with ASD and has an arrangement with the Department of Translational Medical Sciences - University of Naples Federico II.

Inclusion criteria were:

- clinical diagnosis of Autism Spectrum Disorder, in keeping with the diagnostic criteria of the DSM-V, using standardised tools (ADI, ADOS);
- chronological age between 8 and 16 years;
- a rehabilitation plan already underway in accordance with the study's goals;
- native Italian speakers.

Exclusion criteria were:

- physical impairments;
- participant in another research protocol;
- participant with a known organic syndrome and/or non-stabilized neuropediatric (e.g., seizures) or medical (e.g., diabetes mellitus) comorbidities.

The participants' IQ was estimated via the Wechsler Intelligence Scale for Children IV (WISC-IV) [171] and a diagnostic screening was conducted via ADOS-2 [36] in order to evaluate their severity level in compliance with the DSM-V [1].

This study was conducted in accordance with the ethical principles that have their origin in the Declaration of Helsinki, Good Clinical Practice (GCP), and any regional or national regulations, as appropriate. The accordance with these standards guarantees that the laws, the safety and wellbeing of the subjects were safeguarded and data are credible. The study was approved by the Ethics Committee of University of Naples Federico II. All participants' parents gave their informed consent to let them participate in the study. Table 3.2 summarises the characteristics of the participants.

Moreover, the participants' profile was investigated by analysing several aspects linked to the game via a survey filled out by their parents. In particular, following the survey proposed by [172], their use of technological devices (Table 3.3) as well as their interest in videogames (Table 3.4) were investigated. Most participants appeared to have a strong interest in videogames, and all used technological devices such as computers, tablets and smartphones.

Table 3.2: Characteristics of participants. The table summarises the main features of the participants, reporting ASD severity level evaluated through a diagnostic screening, sex, age, and Full Scale Intelligence Quotient.

Participants	**Severity Level**	**Sex**	**Chronological Age**	**FSIQ**
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
Mean (SD)	20% L1, 40% L2, 40% L3	80%M, 20%F	11.90 (2.73)	58.70 (19.30)

Table 3.3: Technological devices used by participants with their functions. The table reports the main technological devices used by participants and to what purpose.

	Participants (N=10)
Technological devices	
Tablet	10
Smartphone	10
Computer	9
Game Consoles (Wii, PlayStation, Nintendo DS, Xbox)	5
Functions of technology use	
Games	7
Music	9
Photos	7
Web	5
Films	6
Social Media	1

Table 3.4: Summary of the participants' interest in commercial videogames. The table reports the use and preferences of the participants about commercial videogames.

	Participants (N=10)
Interest in videogames	
Yes	8
No	2
Interfaces that the participant can use independently to play	
Touchscreen	10
Keyboard and mouse	6
Joystick	6
Kinect	1
Wii	1
Popular videogames played	
Lego Dimension	1
Subway Surf	4
Scooby-do	2
Cars	4
Pro Evolution Soccer	2

3.4 Procedure

The research procedure followed the experimental protocol that we devised. The real-life shopping experiences were carried out in the supermarket chosen for this study, Centro Commerciale Auchan Pompei (SS145, Loc, Via Pontenuovo, 3, 80045 Pompei NA). In these real-life experiences, the participants went to the supermarket accompanied by a therapist, while a researcher recorded the experience with a traditional camera. The therapist guided the participant, providing him or her with a shopping list that had three tasks to complete: (1) pick up the ingredients to cook a dish (pasta with tomato sauce); (2) pick up personal care products; (3) pick up a product to organize a party. The tasks in the shopping list were both written and explained with representative images. The therapist helped the participant only where necessary (e.g., by reading the tasks of the shopping list or by demonstrating the actions to perform if the participant did not know them). The first real-life experience was carried out within 4 weeks of the diagnostic screening. On the other hand, the second real-life experience was carried out within 1 week of the end of the training. The real-life experiences was conducted individually for each participant and they were interrupted if

the participant showed signs of distress or/and irritability, maladaptive behaviour or/and problems.
The virtual training with the serious game took place during the therapy session of the participants at the Centro Medico Riabilitativo Pompei. The game sessions were led by each participant's therapist, who chose the game options according to each participant's needs, while a researcher supervised in case of a technical issue with the game. In particular, the environment setup proposed by Khowaja and Salim [102] was followed, providing a laptop computer with two input devices: a joystick controller and a keyboard with a mouse (Fig. 3.3). Each participant played ten game sessions, one per week, for no more than 30 minutes. Moreover, in each game session, the player could play only one game level.
The diagnostic screening and endpoint evaluations was carried out at the Department of Translational Medical Sciences - University of Naples Federico II.

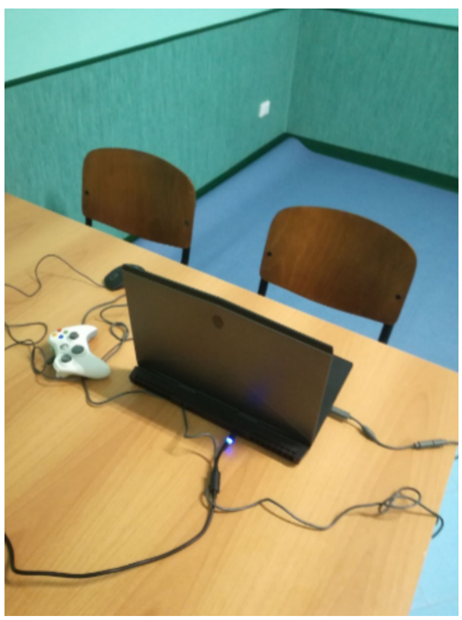

Figure 3.3: Environment setup for the virtual training with *ShopAut*. The figure shows the environment setup for the virtual training with *ShopAut*. A laptop computer was provided, with two input devices: a joystick controller and a keyboard with a mouse.

3.5 Outcome Measures

Assessing real-life experiences involves different variables and aspects – clinical, psychological, and social – which are all dependant on the real environment, as there are no specific assessments available to describe the functioning of the participant in non-clinical context such as the supermarket. Therefore, we elaborated an ad hoc evaluation form based on *International Classification of Functioning, Disability and Health: children and youth version* (ICF-CY)[173]. The two experiences (pre- and post-intervention) were analysed separately by two ICF-CY specialised raters of the research team (a neuropschiatric and a psychologist) who were given instructions regarding the use of the evaluation form. Furthermore, we clinically assessed the intervention outcomes via the *Vineland Adaptive Behavior Scale II* (VABS-II) [174]. The game performance was evaluated analysing the player's action accuracy.

The ICF-CY is a universal multipurpose classification developed by the World Health Organization (WHO) to describe health and health-related states with a standard language. The ICF-CY promotes a biopsychosocial model: functioning and disability originate from the interactions between health conditions and contextual factors, both personal and environmental. Moreover, the ICF-CY is a tool that allows experts to universally share and compare data on the functioning assessment of an individual in their day-to-day life. The ICF-CY is divided in two parts: Functioning and Disability, and Contextual Factors; each part has two components. Each component consists of various domains and, within each domain, categories, which are the units of classification. Health and health-related states of an individual may be recorded by selecting the appropriate category code or codes and then adding qualifiers, which are numeric codes that specify the extent or the magnitude of the functioning or disability in that category, or the extent to which an environmental factor is a facilitator or barrier [173].

Following the ICF user instructions [173, 175], we identified each shopping action and classified the information related to these activities 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. We determined that the information to be coded was consistent with the 4-character level and the 5-character level; we used the first qualifier, that is, *performance*. The *performance* qualifier represents what an individual does in a real environment, so it reflects the functioning in the real setting of a supermarket. The scale of our form followed the ICF-CY scale for the *performance* qualifier (as shown in Table 3.5).

xxx.0	NO difficulty (none, absent, negligible, ...)	0-4 %
xxx.1	MILD difficulty (slight, low, ...)	5-24 %
xxx.2	MODERATE difficulty (medium, fair, ...)	25-49 %
xxx.3	SEVERE difficulty (high, extreme, ...)	50-95 %
xxx.4	COMPLETE difficulty (total, ...)	96-100 %
xxx.8	not specified	
xxx.9	not applicable	

Table 3.5: ICF-CY scale of the *performance* qualifier. The table reports the scale provided by ICF-CY for the *performance* qualifier.

We structured the form around the idea that the shopping actions represented the items to be evaluated in order to assign a value to the *performance* qualifier of a specific ICF-CY code. Since the different actions of a shopping experience belong to the same ICF-CY code, we gathered these actions together in a group of five (or one of its multiples) to facilitate the assignation of a score. In this case, the score of the ICF-CY code was the median of the provided items. If a score of 8 or 9 was assigned to less than half of 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 from two values of the ICF-CY scale. In addition, we identified other ICF-CY codes that are related to the general experience of shopping but cannot be identified as real actions. Table 3.6 shows the checklist of identified ICF-CY codes; the full form can be found in Table 3.7. Furthermore, environmental factors were coded for each participant in accordance with the ICF-CY coding *convention 2* [173] provided for the Environmental Factors component.

Table 3.6: Checklist of ICF-CY codes selected for the evaluation form. The ICF-CY codes were selected by identifying all the actions involved in a shopping activity, as well as several aspects involved in a shopping experience that cannot be considered real actions. Therefore, the ICF-CY codes are gathered into two groups: those related to the shopping activities and those related to the general shopping experience.

ICF-CY codes		
Shopping Activities	**d166**	Reading
	d310	Communicating with - receiving - spoken messages
	d315	Communicating with - receiving - nonverbal messages
	d440	Fine hand use
	d445	Hand and arm use
	d460	Moving around in different locations
	d860	Basic economic transactions
General Shopping Experience	**d161**	Directing attention
	d175	Solving problems
	d177	Making decisions
	d2201	Completing multiple tasks
	d250	Managing one's own behaviour
	d6200	Shopping
	d730	Relating with strangers

Table 3.7: The ICF-CY-based form designed to evaluate performance in the real-life experiences. It was structured in two parts: the first one includes all the ICF-CY codes for the actions in a shopping activity, while the second includes aspects of the general shopping experience.

PART 1: SHOPPING ACTIVITIES

ICF-CY Chapter 1: Learning and applying knowledge

d166 Reading: Performing activities involved in the comprehension and interpretation of written language (e.g., books, instructions, newspapers in text or Braille), for the purpose of obtaining general knowledge or specific information.

Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Reading the messages on the sign near the shopping cart on which coin to use	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Reading the directions outside	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Reading the shopping list	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Reading the directions in the aisles	0	1	2	3	4	8	9	0	1	2	3	4	8	9

Reading the product labels	0	1	2	3	4	8	9	0	1	2	3	4	8	9
d166.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
ICF-CY Chapter 3: Communication														
d310 Communicating with - receiving - spoken messages: Comprehending literal and implied meanings of messages in spoken language, such as understanding that a statement asserts a fact or is an idiomatic expression, such as responding and comprehending spoken messages.														
Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Comprehending the meaning of the instructions concerning the coin to unlock the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the directions outside	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the directions on what to buy	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the directions in the aisles	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehend the meaning of the instructions at the register	0	1	2	3	4	8	9	0	1	2	3	4	8	9
d310.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
d315 Communicating with - receiving - nonverbal messages: Comprehending the literal and implied meanings of messages conveyed by gestures, symbols and drawings, such as realizing that a child is tired when she rubs her eyes or that a warning bell means that there is a fire.														
Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Comprehending the meaning of the arrow symbol on the shopping cart indicating where put the coin	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the images in the shopping list	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the symbols in the aisles	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the product logos	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending the meaning of the symbols at the register	0	1	2	3	4	8	9	0	1	2	3	4	8	9

d315.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
ICF-CY Chapter 4: Mobility														
d440 Fine hand use: Performing the coordinated actions of handling objects, picking up, manipulating and releasing them using one's hand, fingers and thumb, such as required to lift coins off a table or turn a dial or knob.														
Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Taking the coin for the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Putting the coin in the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Gathering the money at the register	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Opening the shopping bag	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Removing the coin from the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
d440.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
d445 Hand and arm use: Performing the coordinated actions required to move objects or to manipulate them by using hands and arms, such as when turning door handles or throwing or catching an object.														
Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Unlocking the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Pushing the empty shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Picking up the products from the shelf	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Placing the products in the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Placing the products on the conveyor belt at the register	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Bagging the products	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Pushing the full shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Removing the shopping bag from the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Putting the shopping cart back in its proper spot	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Carrying the shopping bag	0	1	2	3	4	8	9	0	1	2	3	4	8	9
d445.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**

d460 Moving around in different locations: Walking and moving around in various places and situations, such as walking between rooms in a house, within a building, or down the street of a town.														
Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Moving towards the shopping cart	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Moving towards the entrance of the supermarket	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Moving around the aisles in the supermarket	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Moving towards the register	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Moving towards the exit of the supermarket	0	1	2	3	4	8	9	0	1	2	3	4	8	9
d460.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
ICF-CY Chapter 8: Major life areas														
d860 Basic economic transactions: Engaging in any form of simple economic transaction, such as using money to purchase food or bartering, exchanging goods or services; or saving money.														
Items	**Pre-intervention** *Performance*							**Post-intervention** *Performance*						
Comprehending how much the money is worth	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Distinguishing money	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Paying	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Comprehending how much the change is worth	0	1	2	3	4	8	9	0	1	2	3	4	8	9
Handling money	0	1	2	3	4	8	9	0	1	2	3	4	8	9
d860.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
PART 2: GENERAL SHOPPING EXPERIENCE														
ICF-CY Chapter 1: Learning and applying knowledge														
d161 Directing attention: Intentionally maintaining attention to specific actions or tasks for an appropriate length of time.														
	Pre-intervention *Performance*							**Post-intervention** *Performance*						
d161.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
d175 Solving problems: Finding solutions to questions or situations by identifying and analysing issues, developing options and solutions, evaluating potential effects of solutions, and executing a chosen solution such as in resolving a dispute between two people.														

	Pre-intervention							**Post-intervention**						
	Performance							*Performance*						
d175.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
d177 Making decisions: Making a choice among options, implementing the choice, and evaluating the effects of the choice, such as selecting and purchasing a specific item, or deciding to undertake and undertaking one task from among several tasks that need to be done.														
	Pre-intervention							**Post-intervention**						
	Performance							*Performance*						
d177.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
ICF-CY Chapter 2: General tasks and demands														
d2201 Completing multiple tasks: Completing several tasks, together or sequentially, such as getting up and getting ready to leave for school, shopping and completing errands for a friend while shopping.														
	Pre-intervention							**Post-intervention**						
	Performance							*Performance*						
d2201.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
d250 Managing one's own behaviour: Carrying out simple or complex and coordinated actions in a consistent manner in response to new situations, persons or experiences, such as being quiet in a library.														
	Pre-intervention							**Post-intervention**						
	Performance							*Performance*						
d250.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
ICF-CY Chapter 6: Domestic life														
d6200 Shopping: Obtaining, in exchange for money, goods and services required for daily living (including instructing and supervising an intermediary to do the shopping), such as selecting food, drink, cleaning materials, household items, play-material or clothing in a shop or market; comparing quality and price of the items required, negotiating and paying for selected goods or services, and transporting goods.														
	Pre-intervention							**Post-intervention**						
	Performance							*Performance*						
d6200.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**
ICF-CY Chapter 7: Interpersonal interactions and relationships														
d730 Relating with strangers: Engaging in temporary contacts and links with strangers for specific purposes, such as when asking for information, directions or making a purchase.														
	Pre-intervention							**Post-intervention**						
	Performance							*Performance*						
d730.	**0**	**1**	**2**	**3**	**4**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**8**	**9**

The VABS-II [174] offers a way to measure personal and social self-sufficiency in real-life situations and to observe how these cognitive abilities impact the autonomy management process when put into practice. The VABS-II consists in a semi-structured interview with the parents; the adaptive behaviour is evaluated in the following functioning domains: Communication, Daily Living Skills, Socialization, and Motor Skills, which is meant for children under 7 years. These domains involve different items related to the shopping activities, such as using money or following instructions. The VABS-II was carried out both pre-intervention (before the first real-life experience and during the diagnostic screening of the participants) and post-intervention (after the second real-life experience, at six months from the first VABS-II assessment).

The game performance corresponds to the game score and was calculated on the percentage of the actions accuracy in the game as proposed by Simões et al. [118]:

$$game\ performance = \% \frac{number\ of\ correct\ actions}{number\ of\ expected\ actions}$$

3.6 Statistical Analysis

Clinical assessments and game performances were considered continuous variables, while the ICF-CY scores were considered categorical variables. For continuous variable, the Shapiro-Wilk test was used to assess the data normality in order to choose between a parametric or a non-parametric test in the statistical analysis.

The inter-rater reliability of the ICF-CY scores was calculated from the data obtained from the two independent raters via weighted Cohen's kappa [176]. Cohen's kappa was calculated with 95% confidence. Items that scored 8 in the ICF-CY scale were considered missing values in the statistical analysis. The comparison of paired data (pre- and post-intervention) was analysed via the Wilcoxon signed-rank test, due to non-normality of the data.

The statistical analysis was conducted using R Software (R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/) and a P-value < 0.05 indicated statistically significant differences.

4 Results

This chapter presents the results of data analysis in three sections. The first reports the results related to real-life experiences in pre- and post-intervention. In particular, for pre- and post-training assessment, we used an *ad hoc* form based on the *International Classification of Functioning, Disability and Health: children and youth version* (ICF-CY) [173] to evaluate the participants' functioning in the supermarket. Two raters independently analysed the videos of the real-life experiences to determine the ICF-CY codes. Cohen's kappa statistic was used as the measure of inter-rater reliability. The second section shows the data of paired analysis for the values of the clinical used tool, *Vineland Adaptive Behavior Scale II* (VABS-II). The last section reports the data of the game sessions.

4.1 Real-life Experiences Results

The results of Cohen's kappa statistics report an almost perfect agreement both pre- ($\kappa = 0.96$) and post-intervention ($\kappa = 0.90$) between the two observers. For this reason, we adopted the raters' median as the only actual ICF-CY score.

The values for the ICF-CY codes decrease in post-intervention (Fig. 4.1); and, the Wilcoxon signed-rank test of the ICF-CY data shows statistically significant ($P < 0.05$) differences between the pre- and post-intervention scores, except for the following ICF-CY codes: d315, d440, d730, and d860 ($P > 0.05$). ICF-CY codes d161 ($P < 0.005$), d175 ($P < 0.01$), d2201 ($P < 0.01$), d460 ($P < 0.005$), and d6200 ($P < 0.005$) showed highly significant improvements post training. In Figure 4.2, the trend of the ICF-CY codes is reported for each participant.

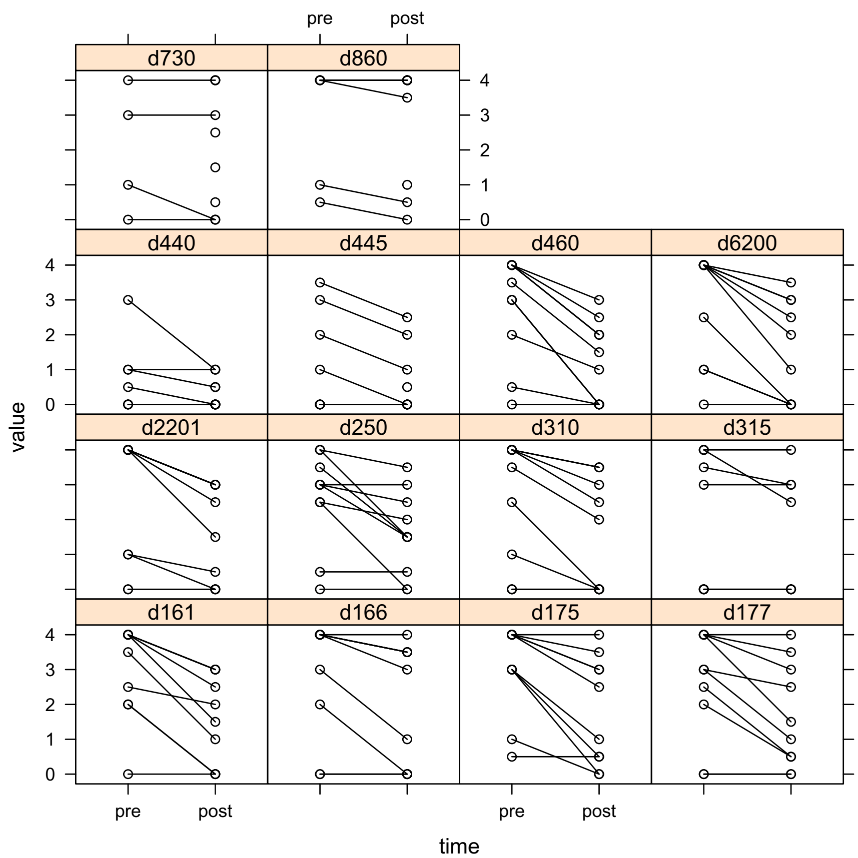

Figure 4.1: Pre- and post-intervention values for the ICF-CY codes. The figure shows paired data (pre- and post-intervention) for the ICF-CY codes selected for the evaluation form.

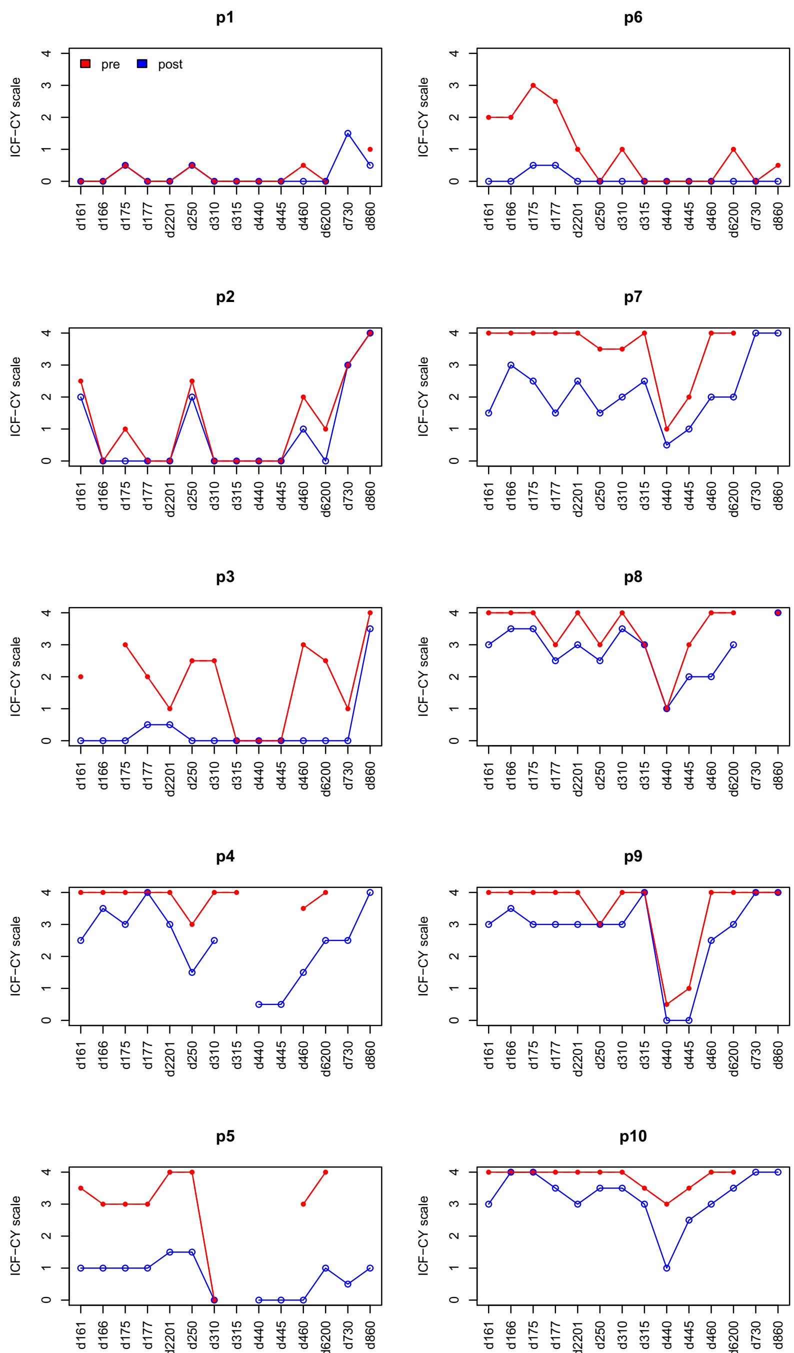

Figure 4.2: Pre- and post-intervention ICF-CY profiles for each participant. The figure shows the profile of each participant; the red line represents the ICF-CY profile in pre-intervention while the line blue is for post-intervention.

In pre-intervention, 4 participants (p4, p5, p7 and p10) did not complete their shopping as they encountered various difficulties, especially in directing their attention, understanding the tasks, and managing their own behaviour; in these cases, the experience was interrupted not to upset the participant. After the training with *ShopAut*, all participants completed their shopping activities. As for environmental factors, environmental barriers were detected in only 3 of the participants; in particular, observers identified sound (e250) as a barrier and they were in total agreement on the score ($\kappa = 1$) for both pre- and post-intervention (Table 4.1).

Table 4.1: Coding of environmental factors pre- and post- intervention following the ICF-CY Convention *2* for the Environmental Factors component. The table reports the coding of environmental factors identified in the real-life experiences pre- and post- intervention.

Participants	Pre-intervention	Post-intervention
P1	-	-
P2	-	-
P3	e250.3	e250.2
P4	e250.4	e250.2
P5	-	-
P6	-	-
P7	-	-
P8	-	-
P9	e250.3	e250.3
P10	-	-

4.2 Clinical Results

In order to assess the effectiveness of the SG-based intervention on the ability of the participants to perform daily activities, we adopted a standardised paediatric functional assessment tool, *Vineland Adaptive Behavior Scale II* (VABS-II). We used the Wilcoxon signed-rank test to compare the pre- and post- values of the VABS-II scales. There was a significant improvement for the Daily Living Skills ($P < 0.005$) and Socialization ($P < 0.05$) scales, as shown in Fig. 4.3. With regard to the Communication scale, despite some values increased, no statically significant (P > 0.05) improvement was detected.

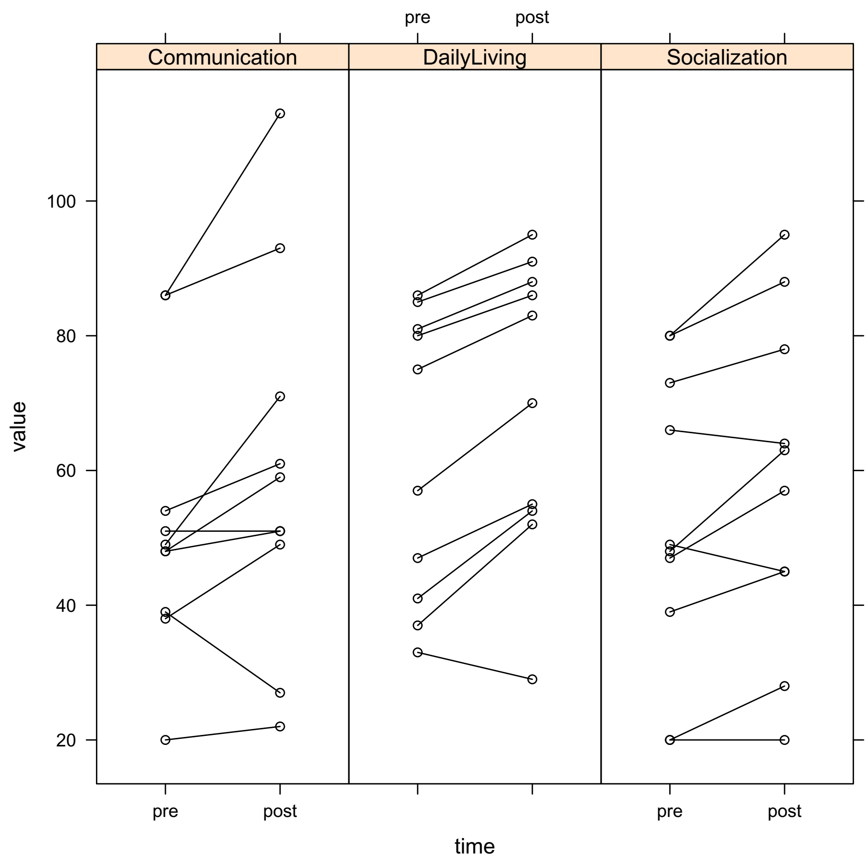

Figure 4.3: Pre- and post-intervention values for the VABS-II scales. The figure shows the values of the VABS-II scales both in pre- and post-intervention.

4.3 Game Results

All participants seemed to enjoy the game and were able to play it without particular difficulties. For game inputs, they mainly preferred the joystick controller as an input device (n=8), with only two participants using the keyboard. We did not identify a specific preference regarding the player character, but players who had experience with commercial videogames usually preferred the first-person perspective. Table 4.2 summarises respectively the player character used and game inputs chosen based on the ASD severity level of the participants.

Table 4.2: Players' preferred input devices during the virtual training with the serious games ShopAut. The table reports the preference of the participants on input devices they could use to play the serious game *ShopAut*.

ASD Severity Levels	**First-person perspective**		**Third-person perspective**	
	Joystick controller	Keyboard with mouse	Joystick controller	Keyboard with mouse
Level 1 (n=2)	1	-	1	-
Level 2 (n=4)	3	-	1	-
Level 3 (n=4)	1	-	1	2

Gameplay data was recorded for every session; in particular, the serious game recorded the game performance, calculated based on the accuracy of the game actions. During the first game session, the participants played the first game level, which is a tutorial level meant to introduce them to the game. The participants only played one game level per session; moreover, except for the tutorial, they could unlock and play the subsequent game level in the next game session only if they had earned a medal in the previous one. All participants earned a medal in each game session, therefore a new game level was introduced in each game session. Figure 4.4 reports the trend of game performances over the game sessions. Game performance shows a linear trend, with a statically significant increasing slope ($P < 0.05$) of 1.47 per week. Analysing the game performances based on the ASD severity levels of the participants, an increase can be observed over the weeks in Level3, with a statistically significant increasing slope of 2.46 ($P < 0.01$), while the trends for both Level1 and Level2 are nearly constant (the slope variations are not statistically significant: $P > 0.05$). Figure 4.5 reports the game performances based on the ASD severity levels of the participants.

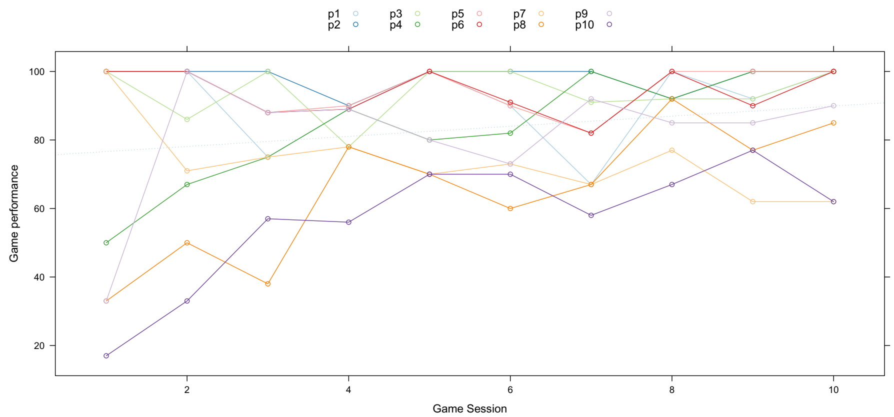

Figure 4.4: Game performances of the participants over the game sessions. The figure shows the trend of game performances during the virtual training with *ShopAut*. The blue dotted line represents the linear trend line of data.

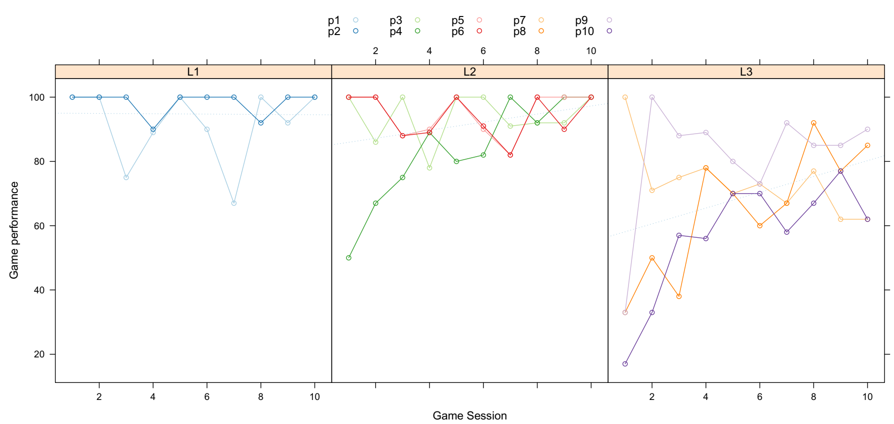

Figure 4.5: Game performances of the participants based on their ASD severity levels. The blue dotted line represents the linear trend line of data.

5 Discussion and Conclusion

In this chapter, the results of this research are presented and discussed with reference to the aim of the study, which was to investigate the use of SG-based interventions to improve daily living skills in people with ASD. More specifically, the first part presents the discussion of the SG design and the game results, highlighting the novel contributions. The second part discusses the actual effects of our SG-based intervention and provides some considerations from of the point of view of rehabilitation and clinical experts involved. Finally, a summary of the present work was provided, offering an overview and a conclusion to the research.

5.1 Discussion

The present study examined how personalised serious games can be effective in improving daily living skills in children and teens with ASD. 10 participants with ASD, aged between 8 and 16 years, played *ShopAut* – our 3D life simulation game – for ten sessions during their regular therapy sessions in order to train daily living skills related to shopping in a supermarket. Several aspects of the serious game were individualised to meet to the different needs of people with ASD, to promote a personalised game experience of training aimed to improve the learning outcome. Before and after training with *ShopAut*, real-life experiences were carried out in a supermarket in order both to observe the participant's performances for shopping activities and to evaluate the generalisation of trained skills. The functioning of the participants in a real-life setting was evaluated via a specific form based on the ICF-CY coding [173], while the clinical outcomes of the intervention were assessed using VABS-II [174].

Serious games can be defined as digital games characterised by an instructional goal and aimed at teaching and training specific skills, behaviours, and knowledge [62]. SG design is a complex process that requires an adequate integration between learning contents and game elements in order to achieve the established educational goals. Therefore, it is essential to promote a multidisciplinary approach to facilitate the design process and to identify the main game elements and serious contents. Following this multidisciplinary approach, the present research involved a multidisciplinary team of experts to design the personalised serious game:

- Biomedical engineering knowledge and experience to coordinate the different involved figures in the SG design, to effectively implement the SG-based intervention, to identify and implement the settings and the dynamics of the serious game, to adapt them to a game-oriented focus, to investigate the personalisation elements in the game, and to plan the SG-based intervention.
- Medical knowledge and experience of a neuropsychiatric to identify common problems of people with ASD and strategies for clinical management and assessment, and to plan the SG-based intervention.
- Rehabilitation knowledge and experience of a psychologist to identify the different problems of people with ASD, learning contents of the serious game, useful rehabilitation strategies, and personalisation elements to consider for the game, and to plan the SG-based intervention in a rehabilitation routine.
- Rehabilitation knowledge of therapists to identify common problems of people with ASD, useful rehabilitation strategies – including the activities conducted, artifacts, and technology used –, personalisation elements to consider for the game and preferences of the players.

In accordance with [55, 151], this study involved the team throughout the whole process of design and development of the serious game.

According to [83, 102, 143, 144, 148, 167, 168], different elements have to be considered when designing a serious game for people with ASD. *ShopAut* incorporates all the key elements of these frameworks; in particular, Table 5.1 shows how these frameworks have been applied to *ShopAut*, following the summary proposed by Carlier et al. [138].

However, alongside those from the mentioned frameworks, this study proposes new suggestions regarding how to personalise serious games for people with ASD. In particular, two innovative elements were introduced in the game: personalisation of game modes based on the ASD severity levels and personalisation of the game scenario. These elements were the result of an exchange of ideas between the different experts of the project team, integrating rehabilitation and clinical considerations with game dynamics. In particular, according to [32, 33], specific strategies need to be identified to support people with ASD; usually, these strategies require different kinds of facilitators that can help to bring out specific skills of the individual. For instance, Gison et al. [177] offered several examples of possible facilitators that can be used in a rehabilitation intervention, such as the "use of specific musics [that] can represent a powerful tool to activate items of communication-social develop such as joint attention, referential gaze or gestures imitations". Based on these considerations, we identified possible facilitators to implement in the game to support the player during the game. The facilitators were evaluated in accordance with the ASD severity levels [1] and included different elements – such as audio to draw attention, point lights directing the player, images and textual messages – based on the different game missions. This way, the player is involved in the game and they are not frustrated by possible game difficulties.

The choice to reproduce the real-life environment is in line with one of the recommendations for the interventions for people with ASD: making the environment predictable [32, 33]. In other words, people with ASD exhibit resistance to changes and new contexts, which is why they require predictability: so that they know and understand what is coming next. Different strategies were adopted to make the environment predictable, such as a storyline, visual aides, pictures of real-life places [163, 178]. From this perspective, serious games can reproduce real-life settings where the player can explore and experiment new contexts and situations, making the environment predictable [48]. For this reason, *ShopAut* was developed as a 3D videogame in order to facilitate the exploration of the game environment and to build an immersive game experience.

Table 5.1: Analysis of the design guidelines integrated in *ShopAut*. The table summarise how the main features of design guidelines for people with ASD were integrated in the serious game *ShopAut*.

Guidelines Element	**Definition**	***ShopAut***	
Customisation	The game must be adaptable to the child's individual preferences and skills.	☑	Personalisation of the game's scenario, contents, difficulty, and user interface; customisation of the game mode, player perspective, and input devices.

Evolving Tasks	The game should grow more demanding as the necessary skills are acquired, to enable progression of the learned skills.	☑	Game difficulty increases over the game levels and the number of tasks increases every three levels as the player progresses through the game.
Unique goal	There should be one unique explicit goal to reach within a gaming session	☑	The explicit goal of the game is to buy products written on the shopping list; only the last few levels include sub-missions.
Instructions	The goal and tasks should be clear before playing and should not rely heavily on text or language.	☑	The goal and task of the game are explained before starting a level.
Reward	Rewards should be offered after a good performance, to increase the child's motivation, engagement and implicitly improve skills.	☑	Once the player completes a level, they earn a different medal depending on the game score they achieved, specifically a gold medal, a silver medal or a bronze medal.
Repeatability and predictability	Repeatability is important to master a skills and creates a certain predictability of the expected game goals for the next session.	☑	The game levels can be repeated as often as the player wants. The goals of the specific level remain the same.
Transitions	Transition times between different game states should be simple and minimised, to avoid loss of attention, and it should be easy to repeat a certain game.	☑	No transitions are provided.
Minimalist graphics	Graphics should be pleasing but functional to avoid distractions and loss of attention.	☑	The user interface has a simple design.

Clear audio	Audio should be used to provide feedback on actions, or complement visual events. Music should be optional and preferably nursery rhymes or classical music	☑	The goal of the music within the game is to set the mood of the world, as well as to provide feedback to the player.
Dynamic Stimuli	To retain the child's attention, it is important to provide animations or music during the entire gaming session.	☑	The game provides facilitators such as audio signals when necessary in order to draw the player's attention
Serendipity	Balance between visual or audio effects that create wonder or surprise, and effects that are predictable and consistent with certain tasks, are important to avoid attention loss.	☑	The game provides a feedback system through textual messages and audio; the game missions appear as textual messages while audio signals are used to draw the player's attention.

The training with the serious game was carried out in the traditional therapy room of the participants during their therapy session. The participants showed interest, enjoyed the game, and did not exhibit particular difficulties with the game. In particular, the possibility to choose the perspective of the player character facilitated the usability of the game based on the players' needs. Usability scales were not used to assess the usability of the software because these scales require specific items to be scored and not all participants were able to provide and convey directly and clearly their opinions regarding the scale items. However, the participants easily learned how to to use the game, thanks to the tutorial level that helps the player understand the game settings and dynamics.

Participants played each game level once and their performance was calculated on the accuracy of the game actions. Overall, game performance values improved over the sessions even as the difficulty increased, as shown in Fig. 4.4. This result may suggest that the personalised design of the game did not create a mismatch between the skill level of the participants and game difficulty. In particular, Level1 and Level2 participants exhibited better game performances, which remained approximately in a range between 70 and 100, excluding the first game session. Instead, participants with Level3 ASD showed a increasing trend in their game performances, but their performances reached a high accuracy level only after the first five weeks. Therefore, all participants responded positively to the new stimuli of the game levels, but Level3 participants required more game sessions to achieve better performances.

Due to the lack of specific tools, the observation of the real-life performance in the supermarket required the creation of a specific form in order to evaluate the participants' functioning. In particular, we adopted the ICF-CY [173] framework because it provides a standardised language for collecting, scoring, and analysing detailed information related to the functioning and disability of an individual. Therefore, we designed a specific form able to identify the ICF-CY codes involved in the shopping experience. 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. More specifically, 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; coordinated hand (d440) and arm (d445) motor actions; walking and moving in different places (d460); self-regulation and self-control (d250); decision-making (d177); problem-solving (d175); relating with strangers (d730); and engaging in any form of economic transaction (d860). However, the form we devised evaluated qualitative variables derived from both behavioural observations and the actions performed in the real-life experiences. For this reason, the real-life experiences were analysed by two expert raters to establish the consistency of the ICF-CY scores. The inter-reliability analysis showed an almost perfect level of agreement between the raters. This result highlights the reliability of our form, which appropriately identified the activities and behaviours involved in the shopping experience.

In the first real-life experience, the majority of participants were disoriented, insecure and, above all, distracted, being unable to focus their attention throughout the shopping activity. In particular, all participants, except p1 and partly p2 and p6, showed different levels of difficulty (ICF-CY scores between 2-4) in almost all ICF-CY codes, as shown in Fig. 4.2. Moreover, the ICF-CY profile is not complete for all participants due to missing values. These values correspond to a score of 8 in the ICF-CY scale and they indicate that there was not sufficient information to code the ICF-CY code. The reason for this lack of information may vary. For participants p4, p5, p7, and p10, some of the ICF-CY codes were not coded because they did not complete the experience. Since the participants did not always relate with strangers in the real-life experience, a critical ICF-CY code to evaluate was d730, which indicates interactions with others. In particular, participants p1 and p8 did not interact with a cashier – a typical interaction with strangers in a supermarket – as there were no cashiers on that day and they had to rely on self-checkout machines instead. For participant p3, the raters did not identify sufficient information to codify ICF-CY code d166 (Reading).

After the virtual training with *ShopAut*, all participants completed the shopping experience, showing increased attention, orientation ability, self-confidence, and knowledge of the shopping procedure. In fact, all participants presented improvements in the monitored ICF-CY codes and the analysis of paired data confirmed statistical improvements for each ICF-CY code except for the following: d315 (Communicating with - receiving - nonverbal messages), d440, d730, and d860. More specifically, as expected, we detected greater decreases in the scores of the ICF-CY codes mainly involved in the training with *ShopAut*. Training with the personalised serious game helped the participants to maintain their attention on specific actions (d161), consequently improving their concentration. Furthermore, *ShopAut* trained their problem-solving skills (d175), providing a variety of issues recreated from possible real-life scenarios in the game levels. *ShopAut* is also set in a real-life supermarket, or rather, it was developed following the real structure of the chosen supermarket. This way, the participants got acquainted with the environment and its structure and organization during the game sessions. Therefore, significant improvements were observed on the ICF-CY code for moving around in different locations (d460), as the participants were able to orientate themselves in the supermarket and walk intentionally down the aisles. In addition, significant improvements were observed on their ability to complete multiple tasks (d2201), and above all, on the overall shopping activity (d6200): the participants proved to be aware of both the shopping phases and the actions to perform. These results confirm the efficacy of our SG-based intervention for people with ASD and proved the generalisation of the trained skills outside the gaming context.

As for the ICF-CY codes that showed no statistically significant improvements, we can observe for example that participants had little difficulty with actions related to ICF-CY code d440 (Fine hand use) even in pre-intervention, while, as previously stated, d730 was a critical ICF-CY to evaluate in the real-life experiences because it presented several missing values, especially in pre-intervention. For ICF-CY code d860, our game did train the participants to identify money and to understand the dynamics of payments, and this intervention represented a first approach to payments for most of them, since the majority of the participants were not aware of the value of money and of monetary dynamics in the social life at the beginning of the study.

Supermarkets are a loud environment with bright lights and a variety of smells that can create problems in people with ASD due to their difficulties in sensorial processing [1]. Our coding of environment factors identified sound as a possible barrier for some people with ASD.

The VABS-II analysis confirmed the effectiveness of the SG-based intervention. More specifically, the paired samples Wilcoxon test showed a statistically significant increment for the Daily Living Skills and Socialization scores. Therefore, the VABS-II showed progress especially in the domains mainly involved in the intervention. The Daily Living Skills scale is representative of the individual's personal, self-care, domestic, and community living skills, while the Socialization scale reflects the individual's interpersonal play or leisure skills, and coping skills. The first VABS-II assessment was performed during the diagnostic screening of the participants, that is, before the real-life experiences and the virtual training, while the second assessment was performed after six months from the first assessment, and thus after all the intervention experiences. Therefore, the VABS-II values are also indicators of the acquisition and maintenance of the trained skills after the intervention and confirmed the generalisation of the trained skills.

This research was carried out in a rehabilitation centre and the SG-based intervention was integrated in the rehabilitation routine of the participants. Therefore, it represented a change not only for the participants, but also for the involved therapists; in particular, as highlighted by all therapists, it was a new experience through which to know their patients, to understand how the participants executed gained skills and knowledge, to reflect on the planning of future interventions, and to investigate new methodologies to support a rehabilitation plan. An interesting reflection from the therapists' point of view was that despite the restricted interests and the difficulty of coping with change – which, as reported by DSM-V [1], are typical behaviours of individuals with ASD – all participants showed a natural curiosity and interest towards this experience that even increased over time. This consideration was supported by different qualitative parameters, such as in the task, positive and enthusiastic expressions (verbal and not), and active involvement.

ShopAut was used during therapy sessions and the game sessions were conducted by therapists that chose the game options and supported the participants where necessary. Moreover, the therapists used the game sessions to interact with players and discuss some elements from the game, such as game objects or game missions. Therefore, the virtual training sessions an experience of joint attention for both therapists and participants, since joint attention was defined as "the capacity to use gestures and eye contact to coordinate attention with another person in order to share the experience of an interesting object or event" [179]. In fact, participants request attention from their therapists through gestures or verbal expressions, sharing their improvements, difficulties, and curiosity. The participants with a developed verbal language asked questions on the game and interacted with their therapists to understand the game missions and to share their impressions; other participants used gestures and facial expressions to involve their therapists.

All therapists perceived the game as a useful tool to train attention on specific tasks, to involve participants in learning the procedural activities of shopping, to develop self-confidence, and to experiment new situations. In particular, as commented by one of the therapists: "I observed that my participants showed growing self-confidence during the game; initially, they followed the game missions and did not try to explore the virtual environment. Little by little, they started to explore the game scenario, to understand fully the different game dynamics, and above all, to feel capable and safe. They realized they could make mistakes without suffering the consequences".

Moreover, they acknowledged the importance of personalisation in providing a positive experience for both gaming and learning. They highlighted how customising the input devices facilitated playability and usability, and how the possible facilitators of the game could help the player in different ways. Furthermore, they perceived the SG-based intervention as a new tool for rehabilitation; in fact, as noted by the therapists' coordinator: "Being involved in the design and development of the serious game enables us, on the one hand, to share our knowledge and professional experience, and on the other, to investigate new approaches and to reflect on future directions. As therapists from different cultural backgrounds, we know the learning power of games in rehabilitation intervention, but sometimes we are biased against digital videogames in a rehabilitation context due to their frequent uncontrolled use among people with ASD, especially at home. However, this experience showed us that SG-based interventions, when properly designed, can be effective".

Indeed, several studies [172, 180] stressed how videogames are commonly used by people with ASD independently because of individual or social-demographics factors. In particular, as reported by Mazurek et al. [180], children and teenagers with ASD spent more than two hours per day playing videogames, and they generally play more than people with other disabilities [180, 181]. Excessive playing can induce a pathological use in adulthood for people with ASD [182, 183], creating addiction and leading to further isolation. Therefore, it is essential to balance the use of videogames and similar applications; consequently, SG-based interventions have to be carefully planned and conveniently integrated in the intervention programme of individuals with ASD. Consistently with this line of reasoning, a personalised SG-based intervention supported by a multidisciplinary approach may need to suggest the correct use of videogame applications to avoid pathological use.

The weak point of this study may be the limited number of patients. The results, although affected by the low sample size, are promising and it would be opportune to increase the number of subjects in order to confirm the outcomes. For this purpose, it would be appropriate to estimate the sample size necessary to reach the 5% probability of type I error and to apply the SG to the whole sample.

In conclusion, several studies have proven that serious games represent a potential tool for people with ASD to learn, experiment, and train specific skills that involve different domains. In particular, there are numerous studies that used SG-based interventions focusing on language skills [102] and emotion [145] but only few investigated the use of these technologies to improve autonomy in everyday life skills. Moreover, despite generalisation being essential in effective ASD intervention [42] and in the consolidation of autonomy and social life in adulthood [184], few studies have assessed the impact of SG-based intervention in real-life contexts. As for the training of daily living skills, only Kang et al. [119]

proposed an assessment of SG-based interventions in a real-life context, and even then, only a small group of participants was involved and the authors provided results based on observational parameters.

However, even technological applications aimed at training daily living skills showed similar limits [185]. In particular, Adjorlu et al. [186] conducted an experimental study that was similar to ours, using virtual reality (VR) training. They developed a VR application to help children with ASD to have a safe shopping experience independently. Even in this experiment, the virtual scene reproduced the real-life supermarket where the participants went pre- and post-training. The effects of the training were assessed through a self-confidence questionnaire and by evaluating the accuracy of the tasks performed in real life. However, only 4 participants were involved, and the results were not confirmed by clinical tools. The authors raised questions regarding the adopted metrics, wondering whether task accuracy could be considered a good parameter of assessment in a real-life context.

This study was the first to investigate the actual improvements after a training with a personalised serious game, providing a detailed assessment of a real-life experience with a standardised tool. Our form makes it possible to describe fully the actions involved in shopping and the several elements of a real-life supermarket, including environmental factors, and different kinds of interactions. Moreover, the results proved improvements in the participants' performance after the virtual training, independently from their ASD severity level. The acquisition and generalisation of trained skills were confirmed by the improvements shown in the VABS-II assessment, one of the most popular tools to assess adaptive behavior of people with ASD [187].

5.2 Conclusion

According to DSM-V [1], Autism Spectrum Disorder is mainly characterised both by deficits in social communication and social interaction, and by restricted and repetitive behaviour. However, ASD can be considered a heterogeneous condition due to its unknown etiopathogenesis, the high variability of the clinical presentations, the intellectual disability, and the several associated comorbidities. Therefore, the disorder always involves a factor of uncontrollability and unpredictability that determines a great diversity among individuals with ASD, enough that one could claim that: "If you've met one person with autism, you've met one person with autism" (Dr. Stephen Shore). Moreover, ASD is considered a lifelong disorder that requires, above all, various kinds of non-pharmacological interventions aimed mainly at minimizing the impact of the core features and associated deficits and at increasing independence at home, at school, and in the community. In particular, these interventions address communication, social skills, daily-living skills, play and leisure skills, academic achievement, and maladaptive behaviors [42].

As reported by Di Rezze et al. [188]: "Supporting the development of daily living skills is particularly important to ensure future independence and successful transitions to adulthood for children with ASD". Moreover, it was detected that difficulties in daily living skills and activities are not correlated to intellectual disabilities but involve all people with ASD, with or without intellectual deficit [189, 190]. Daily living skills and their correlated activities are formed by multiple tasks that can present complex challenges for people with ASD. Therefore, an evidence-based strategy is to divide the tasks into a logical sequence of smaller actions to teach and train these skills [191]. For instance, visual techniques, such as video modeling [192] or visual aides [193], were used to improve the understanding of the different tasks and their logical progression. However, because these techniques only involve watching images or videos, the individual is unable to test their own skills directly during the training. Therefore, technological progress needs to facilitate the development of new training tools, such as serious games, to support the training of specific skills.

And indeed, over the last few decades, interventions based on serious games have become widely used for the treatment of specific ASD symptoms and training of different skills [194]. In particular, the spread of SG-based interventions is due both to the predilection of people with ASD for technology and their videogames use, and to the possibility of reproducing a virtual environment in which they can experiment social situations and learn and train specific skills and knowledge without multi-sensory distractions and stress sources [145, 147]. However, as reported by a recent article [195] published by Spectrum (one of the most prominent websites for news and analyses on advances in ASD research): "Several small pilot studies have produced promising results for games designed to help children with autism, showing that they may improve a range of abilities — including balance, attention and gaze control. The creators of those games are working to prove that those gains persist and translate into real-life benefits. In gaming lingo, they are trying to level up". In other words, research is investigating the effects of SG-based interventions on the generalisation of trained skills to everyday contexts [148].

This study is the result of multidisciplinary work and contributions to research on the effectiveness of SG-based interventions aimed at helping young subjects with ASD improve autonomy and train specific skills, specifically, daily living skills. In particular, this study focused on learning shopping activities to improve the involvement of people with ASD in this familiar activities, to recognise the need to do shopping in order to satisfy one's own needs, and to promote greater self-confidence in loud environments such as supermarkets. As noted by National Autistic Society [196]: "Trips to the shops can be stressful for autistic adults and children. Stress can affect behaviour and can have a profound effect on a person's ability to do day-to-day activities like shopping. Frustration or anxiety can be caused by not knowing why we need to shop or what will happen when shopping, and a person can be overwhelmed by sensory experiences at the shops". Therefore, shopping in a supermarket can become a challenge for people with ASD that do not recognise this activity as a functional activity to living.

Following the different ASD International Guidelines [30, 32, 33], an individualised approach was adopted for the intervention, leading to the design of personalised serious game *ShopAut*. The game was personalised following the different frameworks proposed by the scientific community, adding new elements of personalisation and customisation in order to provide an individualised training experience.

10 young subjects with ASD were involved in this study and played *ShopAut* for 10 sessions, once per week, during their therapy sessions. Before the training, they underwent a real-life experience in a supermarket in order to let us assess their skills and functioning at baseline time. After the training with *ShopAut*, the real-life experience was repeated to assess the outcomes of the SG-based intervention and to evaluate the generalisation of the trained skills. The comparison between pre- and post-intervention was carried out through standardised tools; in particular, a form based on the ICF-CY framework [173] was elaborated to assess the functioning of the participants in the real-life experiences, while a standardised clinical tool, VABS-II [174], was used to confirm the

observational outcomes clinically.

At baseline, all participants showed several difficulties in the real-life experience, since they had not been usually involved by their parents in the family shopping activity. They were mostly confused, not knowing the procedure of shopping, and for some of them that was even their first experience in a supermarket. Moreover, 4 participants did not complete the experience, as they started exhibiting resistance or malaise. After the virtual training with *ShopAut*, all participants completed their real-life experience, demonstrating to have acquired the skills needed for a shopping procedure and its different tasks. Moreover, significant improvements were detected in their ability to maintain attention to specific actions and complete multiple tasks. The improvements were confirmed by the results of the VABS-II analysis that showed statistically significant increments, especially in the values of the Daily Living Skills.

Overall, the present study provides good evidence for the use of personalised serious games in rehabilitation interventions for children and teens with ASD. In particular, it proved that training with a serious game, especially one that is personalised and tailored on the user's needs, can promote the generalisation of trained skills to a real-life setting. Training with a personalised serious game can effectively facilitate the involvement of the player, who can experiment new situations, train skills, and acquire knowledge while playing, all in a safe environment.

Furthermore, this study presents a new methodology for the assessment of SG-based interventions. While few studies have analysed the development of new measures based on the ICF-CY [197], our findings encourage its use to record and observe intervention outcomes, documenting improvements and facilitating the comparison and sharing of data in a standard language. In particular, this approach can be used to develop new tools that can facilitate multidisciplinary work while promoting an integration of SG-based interventions in clinical rehabilitation. In this view, serious games are support tools that can help a rehabilitation team to devise interventions focused on training specific abilities. The aim of this research is also to prove that SG-based intervention, when adequately designed, can be a useful tool in a rehabilitation routine and not just in research. It is an ambition of this work not only to become a reference point for future directions in this research field, but also to work as a model for developing new, cheaper devices for rehabilitation, educational, and health services or concerned parents.

One of the reasons behind the growing research on SGs and technologies-based intervention aimed at people with ASD is to decrease costs. In fact, the costs associated with ASD interventions are excessive, not only for society but for the families, compromising even further the family's well-being. For instance, in the US, between $11.5 billion billions – $60.9 billions are spent per year for children with ASD, while in the UK £1.5 million (US $2.2 millions) are spent for people with ASD with intellectual disability and £0.92 million (US $1.4 million) for individuals with ASD without intellectual disability [198]. Expenses increase in adulthood due to the cost of residential care as well as loss of productivity, underemployment, and unemployment among adults with autism [199]. Therefore, it is essential both to support traditional intervention with economical tools and to promote intervention aimed at improving autonomy and independence of people with ASD.

This thesis is a promising start for further research to develop personalised SG-based intervention for people with ASD to improve autonomy and develop specific skills, such as daily living skills. In particular, with reference to SG personalisation, future works should study how to integrate innovative techniques used in commercial videogames, such as Artificial Intelligence, in order to dynamically adapt and personalise the game on the player's reactions and to investigate behaviours of players with ASD. However, this represents a new field of research in the development of all kinds of serious games, and it is a currently unexplored dimension in SGs for people with ASD. So far, machine learning techniques were featured only in two studies [96, 98], and for diagnostic purposes (i.e., detecting ASD in children).

Furthermore, future works should longitudinally explore outcomes of SG-based interventions to assess the maintenance of the skills over time and investigate the generalisation in other real-life contexts. As a matter of fact, the number of people with ASD engaged in SG-based interventions should be increased by involving different structures or by improving international cooperation networks, both to enlarge the size of the sample and to achieve an actual integration of SG-based interventions in a rehabilitation routine. Moreover, despite the different applications, it is essential to standardise the experimental settings of SG-based interventions in order to improve comparison between studies. This contribution proposes an experimental protocol and provides standardised tools to universally facilitate the sharing and comparing of data.

In conclusion, ASD represents a challenge for researchers of different fields, for society, and its services: all are called to respond to different needs, to detect the different nuances of the disorder, to provide support tools, to investigate the causes, to give guidelines of treatment, to support the families and caregivers, and above all to guarantee the best level of functioning to people with ASD. Technological developments have been inevitably changing the treatment of people with ASD, providing several technological applications. Serious games represent one of the most used computer-based interventions for people with ASD to support training on a variety of skills. However, as reported by Jouen et al. [136], several limits have been found: "(1) most of them have limited capabilities and performance in actual interactive conditions; (2) the majority target high-functioning ASD individuals only; (3) their clinical validation has rarely met the evidence-based medicine standards; (4) the game design is not usually described; (5) they have rarely proven their ability of generalization to everyday life." This research has tried to overcome these limits by promoting a multidisciplinary approach that provides a more robust methodology to assess serious games efficacy, especially in real-life contexts, and an effective, personalised intervention that can be adapted to the whole spectrum of functioning of people with ASD.

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Appendix

A1 Game Design Document of the serious game *ShopAut*

The present document describes the features of the serious game *ShopAut*. It is based on elements discussed in various meetings and involving all members of the research team.

A1.1 Description

The serious game *ShopAut* is a three-dimensional game conceptually based on classic 3D life simulation games and was developed as a computer application. *ShopAut* was devised for Italian players and implements graphics that are friendly for children and teens. It provides a realistic shopping experience where the player can practice and engage with, above all, shopping activities, experiment their problem-solving skills, take on unexpected events, and interact with others.

ShopAut takes place in a supermarket and provides two game environments: the supermarket and its parking lot. Before beginning to play, the player can customise the game options and select the game level; a new level is only unlocked after the player has completed the previous one. The game starts by introducing the main character, Nello, who asks the player to help him buy certain products from his shopping list. The player can then move through the two game scenarios, interacting with all the objects that can be useful for shopping. The shopping game experience is interactive and the player can select the products through a fictional barcode scanner positioned on the shopping cart. Buying products is the main mission, but other sub-missions are provided during the game. The game score is calculated based on the accuracy of the game actions, and the player can be awarded gold, a silver or a bronze medal at the end of each game level.

A1.2 Design Goals

The serious game's main purpose is to improve skills related to a specific daily living activity: shopping in a supermarket. In particular, the game aims:

1. to teach the shopping procedure;
2. to reinforce the categorization and recognition of objects, improving spatial and visual perception;
3. to improve orientation and motor-action patterns in big, loud environments, such as a supermarket;
4. to improve problem-solving skills;
5. to help engage in simple economic transactions;
6. to enhance attention span and concentration;
7. to boost observation skills and attention to detail.

A1.3 Target Audience

Our ideal user has the following characteristics:

- children or teens with ASD, both males and females;
- 8 to 16 years old;
- shows affinity with technology;
- likes and plays videogames;
- uses technological gaming devices, such as PCs, tablets, consoles.

A1.4 Influences and Sources

We reviewed several serious games developed for people with ASD, with a specific focus on three-dimensional games in order to get an idea of the right look and feel for this game, as well as to generate concepts for the gameplay, story, and interactions. We looked especially at modern apps and videogames reproducing shopping experiences, such as: Supermarket Game (https://play.google.com/store/apps/details?id=com.bubadu.supermarket&hl=en_US), Funny Supermarket – Shopping for all Family (https://play.google.com/store/apps/details?id=com.hippo.SupermarketForKids) and Supermarket Shopping Mania 3D (https://play.google.com/store/apps/details?id=com.sgs.supermarket.shopping3D).

A1.5 Characters

- *Nello*: is the main character of the game. He is a child and gives the player game missions and instructions. In the first-person perspective, Nello is a support character and the player does not control him, while the in third-person perspective, Nello himself is controlled by the player and becomes the player character.

- *People in the supermarket*: the characters that shop in the supermarket. As they are not under the direct control of a player, they are defined as non-playable characters (NPCs).
- *Cashiers*: the cashiers of the supermarket that interact with the player at the cash register. They're NPCs, too.
- *Secondary characters - quest givers*: several NPCs that require different information and give the player different side missions. Their presence may vary depending on the game level.

A1.6 Storyline

The storyline is simple: the main mission consists of helping Nello to do the shopping. The number of items in the shopping list changes depending on the game level, but they are all connected to the three main chosen tasks: (1) picking up the ingredients to cook a dish (pasta with tomato sauce); (2) picking up personal care products; (3) picking up a product to organize a party. As the game progresses, different side missions are provided through interactions with people in the supermarket and unexpected events. For instance, there are men working in the supermarket due to an electrical breakdown; a man who lost his wallet and asks for help finding it; shopping with a time limit. Each level introduces a new mini-challenge for the player.

Dialogues are in Italian and clearly worded, as can be seen in the following line from the first meeting with Nello:

Nello: *"Ciao, come stai? Io sono Nello! Mamma mi ha chiesto di comprare delle cose ma è la prima volta che vengo da solo al supermercato. Puoi aiutarmi?"*
"Hi, how are you? My name is Nello! My mom asked me to buy some products but this is the first time that I go shopping alone. Can you help me?"

A1.7 Game Scenario

ShopAut is set in a cartoon styled, present-day world and includes all objects and elements from the real world, as the game scenario reproduces a real supermarket: Centro Commerciale Auchan Pompei (SS145, Loc, Via Pontenuovo, 3, 80045 Pompei NA). It is structured across an outside and an indoor environment: the outside reproduces the parking lot of the supermarket (Fig. A1.1) while the indoor environment reproduces the actual structure of the supermarket (Fig. A1.2).

Figure A1.1: Outside of the real-life supermarket chosen as game scenario for the serious game *ShopAut*. The image shows the outside of the real-life supermarket where the participants went during the real-life experience. This scenario was reproduced as a game scenario in the serious game *ShopAut*.

A1.8 Player

The game provides both a first-person and a third-person perspective. In the first case, the player graphical perspective is rendered from the viewpoint of the player character, and the player can control the camera. In the second case, the graphical perspective is rendered from a fixed distance behind and slightly above the player character (Nello), and the player cannot control the camera.

Actions that the player can perform are:

1. moves back and forth;
2. moves left and right;
3. jump up;
4. grabs the shopping cart;
5. selects the products, shooting via a fantasy barcode scanner;
6. puts the shopping cart back to its place;

Figure A1.2: Indoor of the supermarket chosen as game scenario for the serious game *ShopAut*. The image shows the indoor of the real-life supermarket where participants went during the real-life experience. The indoor of the virtual supermarket was reproduced following the real-life structure and features of this supermarket.

7. selects menu options and game options, such as the money to unlock the shopping cart and to pay.

In Figure A1.3 and A1.4, game controls are reported for the joystick controller and the keyboard with a mouse, respectively.

Figure A1.3: The player commands for the joystick controller in *ShopAut*. The figure shows the commands to play with a joystick controller, developed for the serious game *ShopAut*.

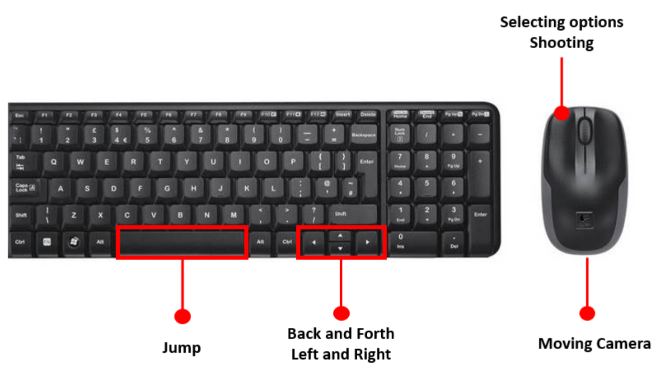

Figure A1.4: The player commands for the keyboard and mouse in *ShopAut*. The figure shows the commands to play with keyboard and mouse, developed for the serious game *ShopAut*.

A1.9 Game Scenes

ShopAut is a three-dimensional serious game that provides different game scenes following primarily the steps of a shopping activity (as show in Fig. 3.1). However, some game scenes were developed with 2D graphics to facilitate understanding of tasks and selection (e.g., selecting coins, payment). The scene graphics adopt a cartoon style, especially in 2D scenes. In order to recreate the sequence of these activities, the game is structured in the following scenes:

- *Main Menu*: in 2D; where the player can select the game options.
- *Parking Lot*: a 3D environment that the player can explore; it reproduces the parking lot of the supermarket. It was the first scene and it is where the game starts. Moreover, here the player meets Nello and executes the actions for taking, unlocking, and locking the shopping cart.
- *Coin*: in 2D; where the player has to select the right coin to unlock the shopping cart.
- *Shopping List*: in 2D; a non-playable scene informing the player of the items in the shopping list.
- *Supermarket*: a 3D environment that the player can explore; it reproduces the indoor of the supermarket. Here, the player can search for and select the products and interact with the different characters.
- *Payment*: in 2D; where the player has to select money to pay the products based on the shopping receipt. In the last few levels, the player has to choose the correct number of bags as well.

These scenes are present in each level; the flow of the game scenes is shown in Figure A1.5.

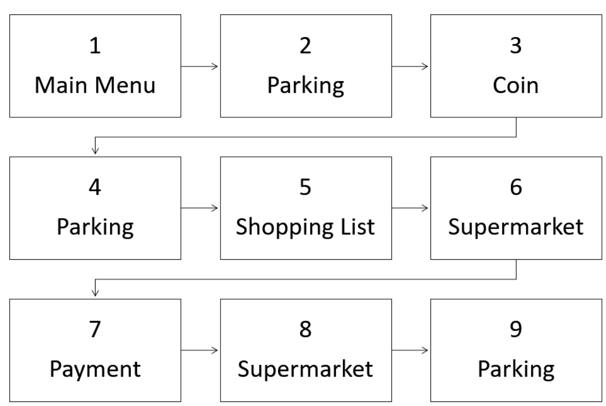

Figure A1.5: The flow of *ShopAut*'s scenes. The figure shows how the game scenes follow one another in the game.

A1.10 Levels

The game consists of ten levels of increasing difficulty. The player can select a level through the main menu, but they can only unlock a new level after they have completed the previous one, earning a medal.

The first level works as a tutorial and introduction to the game. Every three levels as the player progresses through the game, the number of tasks in the shopping list increases. Level 2, 3 and 4 provide one task; Level 5, 6 and 7 provide two tasks; Level 8, 9 and 10 provide three tasks. Starting from Level 5, distractions and realistic audio are introduced. Table A1.1 reports a brief description for each level.

Table A1.1: Description of each level of the serious game *ShopAut*. The table summarise the main features of each game level of the serious game *ShopAut*.

Game Level	Description
1	Tutorial level to introduce the player to the game.
2	The shopping list provides one task: buying the ingredients for a dish (pasta with tomato sauce). The ingredients are brand-specific. This level does not include interactive payment.
3	The shopping list provides one task: buying personal care products. The number of products to pick up is provided. This level does not include interactive payment.
4	The shopping list provides one task: buying products to organize a party. The products have a specific colour. This level does not include interactive payment.
5	The shopping list provides two tasks: buying the ingredients for a dish and personal care products. The number of products to pick up is provided. This level includes easy, interactive payment; the player is not required to select the correct number of shopping bags needed. Unexpected event: some products have been moved from their original position in the previous levels.
6	The shopping list provides two tasks: buying products to organize a party and one personal care product. The party is for a birthday; a personal care product for the guests is also required. This level includes easy, interactive payment; the player is not required to select the correct number of shopping bags needed.
7	The shopping list provides two tasks: buying the ingredients for a dish and food for a party. This level includes easy, interactive payment; the player is not required to select the correct number of shopping bags needed. Unexpected event: aisles being locked due to works.
8	The shopping list provides the main three tasks without instructions; the player has to fulfil them as they wish. This level provides interactive payment including a mathematical formulation; the player is required to select the correct number of shopping bags needed. Unexpected event: the player has to help an NPC to find his wallet.
9	The shopping list provides the main three tasks without instructions; the player has to fulfil them as they wish. This level provides interactive payment including a mathematical formulation; the player is required to select the correct number of shopping bags needed. Unexpected event: the player has to wait for their own turn at the cask register.
10	The shopping list provides the main three tasks without instructions; the player has to fulfil them as they wish. This level provides interactive payment including a mathematical formulation; the player is required to select the correct number of shopping bags needed. Unexpected event: shopping with a time limit.

Moreover, each level provides different game facilitators depending on the game mode. The facilitators change depending on the level and the game missions.

For instance, in Level 2 for game mode 3, the preferential route is signaled by arrows and point lights directing the player, and audio signals are given when necessary in order to draw the player's attention. Moreover, the shopping list includes helpful images and the products to buy are highlighted by colorful lights in order to facilitate recognition. Dialogues are conveyed through written and audio messages.

In Level 2 for game mode 2, audio signals are also provided when necessary to draw the player's attention, and the shopping list includes images and textual messages. Dialogues are conveyed through written and audio messages.

In Level 2 for game mode 1, the items of the shopping list are provided with images and textual messages. Dialogues are conveyed through written and audio messages.

A1.11 User Interface

The User Interface (UI) has a simple design reproducing the possible visual facilitators and the written messages for each game mission, instructions, dialogues, and feedback. The written messages appear in a separate panel on top of the screen for game missions/instructions, at the bottom for dialogues, and in the middle for the feedback. Moreover, the UI shows the shopping list on the upper left of the screen. A description of the UI elements for the different game scenes is reported with equivalent mockups.

- *Splash*: this is the initial screen with the Unity logo (Fig. A1.6).

Figure A1.6: UI Mockup of *ShopAut*'s initial screen. The figure shows the mockup of the user interface at the launch of the game.

- *Main Menu*: presenting all of the possible choices to the player (Fig. A1.7).

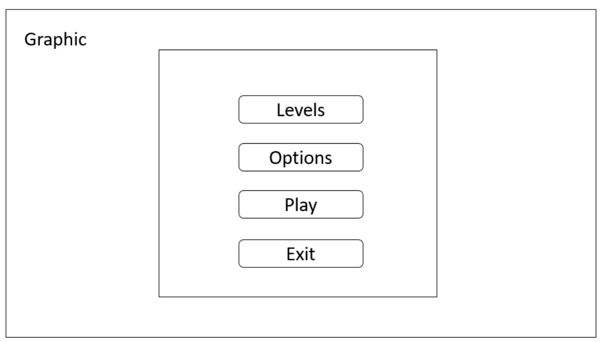

Figure A1.7: UI Mockup of *ShopAut*'s main menu. The figure shows the mockup of the user interface for the main menu. In particular, four options are provided for the player, who can select the game level, select the game options, start or exit the game.

- *Level Menu*: a gallery where the player can check all of the earned medals and select the game level (Fig. A1.8).

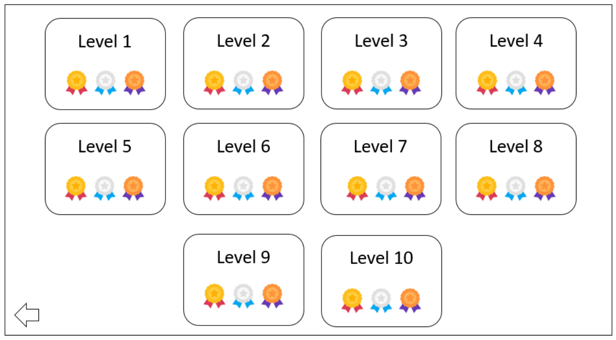

Figure A1.8: UI Mockup of *ShopAut*'s Level menu. The figure shows the interface of the menu where the player can choose a game level. For each level, earned medals were provided.

- *Option Menu*: gives the player the ability to control some of the game's attributes, such as game mode and player perspective (Fig. A1.9).

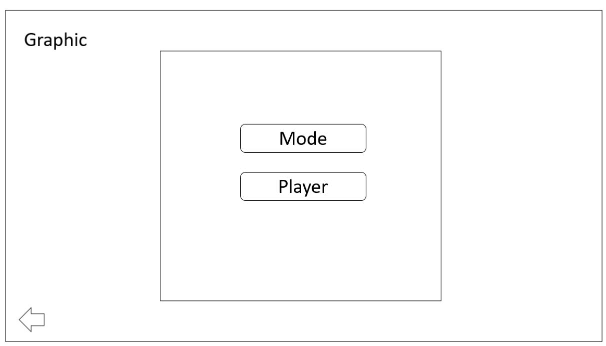

Figure A1.9: UI Mockup of *ShopAut*'s Option menu. The figure shows the user interface of the Option menu. The player can select their preference on input devices and game modes.

- *Parking Lot*: the first scene where the game starts (Fig. A1.10).

Figure A1.10: UI Mockup of the scene *Parking lot*. The figure shows the user interface for the first game scene. The game missions and instructions appear in a separate panel on top of the screen, feedback appears in the middle and dialogues are shown at the bottom.

- *Coin*: where the player can select the coin to unlock the shopping cart (Fig. A1.11).

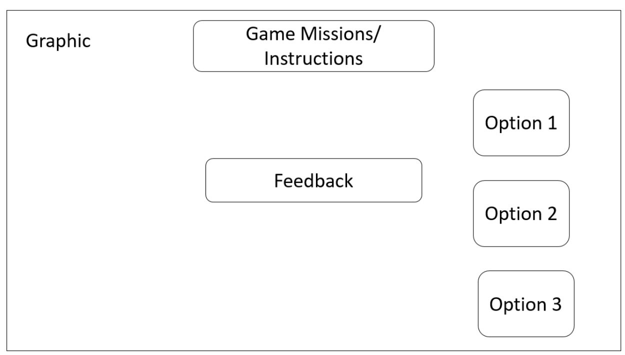

Figure A1.11: Mockup of the scene *Coin*. The figure shows the user interface of the scene where the player can select the coin to unlock the shopping cart.

- *Shopping List*: informs the player of the items in the shopping list (Fig. A1.12).

Figure A1.12: UI Mockup of the scene *Shopping List*. The image reports the mockup of the user interface that shows the shopping list to the player.

- *Supermarket*: where the game is mostly set; a mission and instructions are provided (Fig. A1.13).

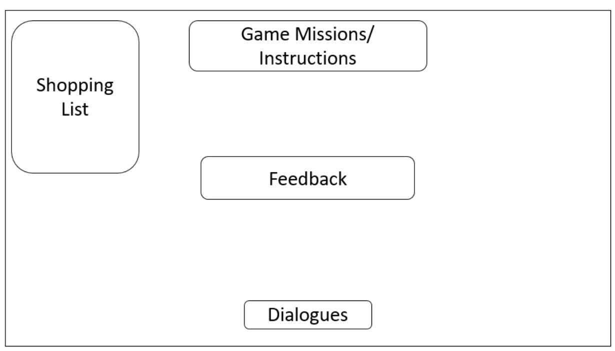

Figure A1.13: UI Mockup of the scene *Supermarket*. The figure shows the user interface of the scene where the player can do the shopping. The structure is similar to the scene Parking Lot, but in this case a panel was provided to remind the player what to buy.

- *Payment*: where the player can select money to buy the products (Figure A1.14).

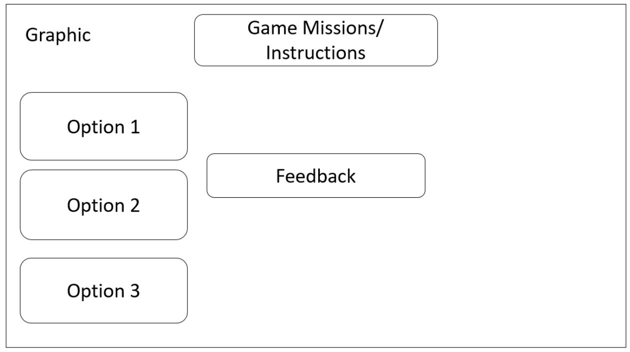

Figure A1.14: UI Mockup of the scene *Payment*. The figure shows the user interface of the 2D scene of the payment where the player had to select the money to buy.

A1.12 Game Score

Following the checklist of the shopping activities (Fig. 3.1), the game score is calculated based on the accuracy percentage of these activities, according to Simões et al. [118]. The game score represent the game performance during the game session. Once the player completes a level, they receive a different medal depending on the game score they achieved, specifically a gold medal (80 < game score 100), a silver medal (50 < game score 80) or a bronze medal (30 < game score 50).

$$game\ score = \% \frac{number\ of\ correct\ actions}{number\ of\ expected\ actions}$$

A1.13 Sound and Music

The goal of the music within the game is to set the mood of the world as well as provide a feedback to the player. There are two clearly different music soundtracks: a basic gameplay music loop that is not too fast can be heard in the first fourth levels; subsequently, the audio reproduces real-life contexts, with noise and supermarket-specific sounds, such as radio transmissions and announcements. However, the noise depends on the game modes; for example, less noise is present in game mode 3. In addition, two different sounds are included for negative and positive feedback respectively.

A1.14 Technical Specifications

Unity [81] (version: Unity 5.6.6f2 Personal (64) bit) was chosen for the game engine. A game engine is a system designed to develop games for various platforms like consoles, computers, and handheld devices like smartphones. 3D Studio Max (https://www.autodesk.it/products/3ds-max/overview) was employed as a 3D modelling software. Autodesk Character Generator (https://charactergenerator.autodesk.com/) and Mixamo (https://www.mixamo.com/#/) were chosen for the creation of the characters and their animations respectively.

ShopAut was produced as a Windows PC application with two input devices: joystick controller and keyboard with mouse. It requires a PC with Windows 10 Home 64 bit, 16GB RAM and Intel Core i7 7th Generation in order to guarantee the best performance. The PC version of the game was supplied on a USB Flash Drive.

A2 Development of the serious game *ShopAut*

This appendix is a technical report on the development phase of the serious game *ShopAut*. The author of this thesis is the game developer of the serious game, but all the members of the research team worked together throughout the entire development process; in fact, several meetings were organized to review the game prototypes and fix possible problems.

The development phase consists of devising the design plans as defined in the GDD and of implementing of game prototypes and the full game. More specifically, the development for *ShopAut* followed these main steps of implementation:

1. Modelling of the game scenes.
2. Modelling of characters and their animations.
3. Development of the game dynamics.
4. Development of the game levels.
5. Modelling of the main menu.
6. Building of the game.

The game engine Unity was chosen to manage and develop the serious game. The game engine was integrated with a 3D modelling software, 3D Studio Max, and two programs for creating and animating characters, Autodesk Character Generator and Mixamo.

A2.1 Modelling of the Game Scenes

The modelling of the game scenes consists in the development of the game environments, or rather, the settings where the game takes place. The scenes were developed completely in Unity and their implementation followed the sequence in which they appear during the game, as shown in A1.5. In order to reproduce the real-life structure of the chosen supermarket, different surveys were carried out to collect images and to create a map of the environments. This information was used as a reference for the design of the three-dimensional environment of the game, especially for the *Parking lot* and the *Supermarket* scenes.

Game development started with the modelling of 3D game scenes, especially the *Parking lot* scene. The game terrain was created with "Unity GameObject", type "Terrain", which enables adding vegetation (e.g., trees, details), making adjustments to the relief like rise land to form mountains, and texture painting. After creating the terrain, it was modelled based on the features of the scene, reproducing vegetation, modelling mountains, applying the different textures of the terrain and defining the core of the game scene (as shown in Fig. A2.1). Subsequently, game objects were inserted on the scene, as shown in Figure A2.2. The same process was followed to create the 3D scene *Supermarket*; Figure A2.3 show various parts of the *Supermarket* scenario with some details of this game scene. Three types of objects were used: (1) downloaded from the Unity Asset Store (https://assetstore.unity.com/) or the Paint 3D Library; (2) modelled with 3D Studio Max, in case of specific characterising objects; (3) modelled with "2D-3D GameObject" in Unity, applying specific textures. Table A2.1 reports a list of scene objects for the various game scenes with their type.

Table A2.1: List of objects per scene with their type. Table reports 3D game objects used for the development of the serious game *ShopAut*. They can be downloaded from the Unity Asset Store (1), modelled using 3Ds Max (2) or Unity "GameObjects" (3).

Type of scene object	**Scene objects**
1.Downloaded from the Unity Asset Store and Paint 3D Library	road, traffic signs, sidewalk, cars, houses, bushes, lampposts, shopping carts, billboards, fictional scanner barcode, food, products, lights, chairs, stools, tables, glasses, decorative objects.
2.Modelled using 3Ds Max	shopping cart rack, cash register.
3.Modelled using Unity "GameObjects"	the supermarket building, signs, vases for plants, fliers, scaffolds of the supermarket, products, counters, posters, boxes, decorative objects, explanatory signs over the aisles.

The 2D scenes were developed following the mockups as shown in the Game Design Document. Interactive buttons were created for scenes *Coin* and *Payment* using specific Unity objects. 2D graphics were chosen in line with the theme of the game scenes. The game contents change depending on the game level; Figure A2.4 and Figure A2.5 show the baseline structure for scenes *Coin* and *Payment* respectively. The *Shopping List* scene shows the player the tasks in the shopping list and provides only one button to

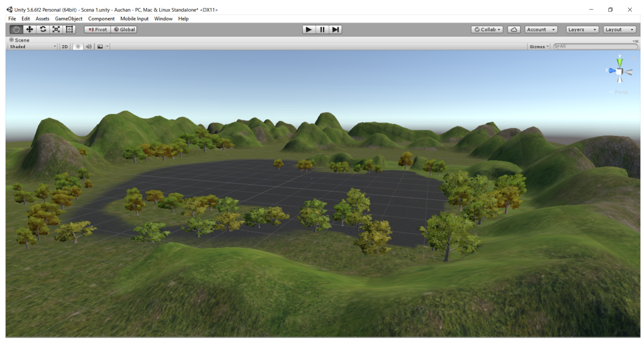

Figure A2.1: Screenshot of the *Parking lot* scene before inserting objects. The image represents the initial structure of the scene *Parking lot*, before inserting the game objects and modelling the full scene.

go to the subsequent scene; its structure is shown in Figure A2.6.

A2.2 Modelling of Characters and Their Animations

After defining the game scenario, characters were modelled and inserted in the game scenes in order to develop the game dynamics. In particular, the Unity standard player, "FPS Controller", was used for the player character in the first-person perspective. This character is already animated via standard scripts and the input commands can be set by changing the parameters in the relative scripts. Input commands were thus customised for the chosen inputs devices, following the GDD sets (Figure A1.3 and Figure A1.4). In particular, walking speed, camera rotation, and sensitivity were accurately set in order to improve gameplay. "FPS Controller" provides a camera that replaces Unity's main one in order to give an immersive perspective, as shown in Figure A2.7.

For the third-person perspective, the character Nello was animated in order for him to be controlled by the player. Nello was chosen from the Unity Asset Store - Character Pack: Free Sample (shorturl.at/ipvY8). In this case, standard animations were edited through scripts to improve player control and a specific script was implemented so that the main camera can follow the character. Figure A2.8 shows the third-person perspective. The other characters were modelled using Autodesk Character Generator and were animated using Maximo. With Autodesk Characters Generator, 3D characters can be created out a catalog of

Figure A2.2: Screenshot of the *Parking lot* scene. The images shows the final modelled scene after inserting all game objects.

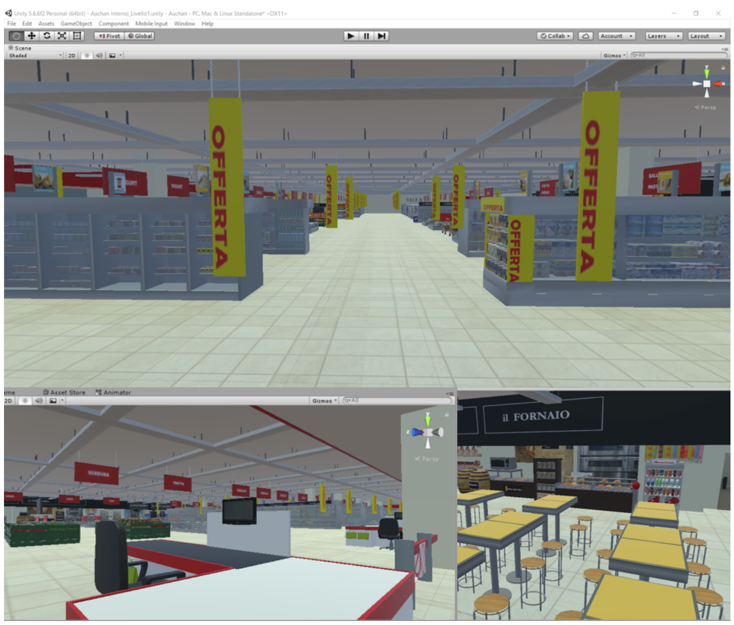

Figure A2.3: Screenshot of the indoor of the virtual supermarket. The figure represents the scene *Supermarket*; a) Screenshot of the central aisle as shown in Figure A1.2. b) Screenshot of the cask register. c) Screenshot of the refreshment area.

Figure A2.4: Screenshot of the baseline structure of scene *Coin*. The figure shows the structure of the scene *Coin*. The game missions and instructions appear in a separate panel on top of the screen, the game choices appear on the right, while feedback appears on the left after the player selects one of the possible choices. The choices change over the game levels and depend on the game mode.

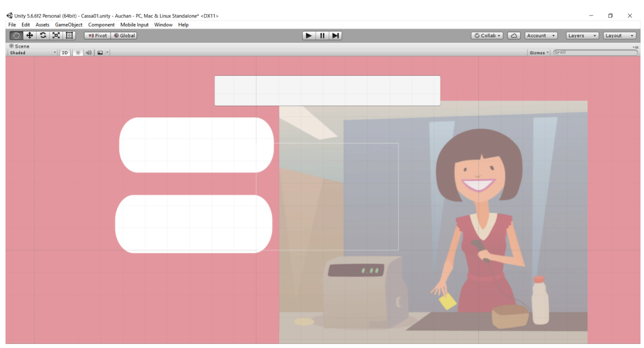

Figure A2.5: Screenshot of the baseline structure of scene *Payment*. The image shows the structure of the scene *Payment* with its panel for the UI. The game missions and instructions appear in a separate panel on top of the screen, the game choices appear on left, while feedback appears on the right after the player selects one of the possible choices. The choices change over the game levels and depend on the game mode.

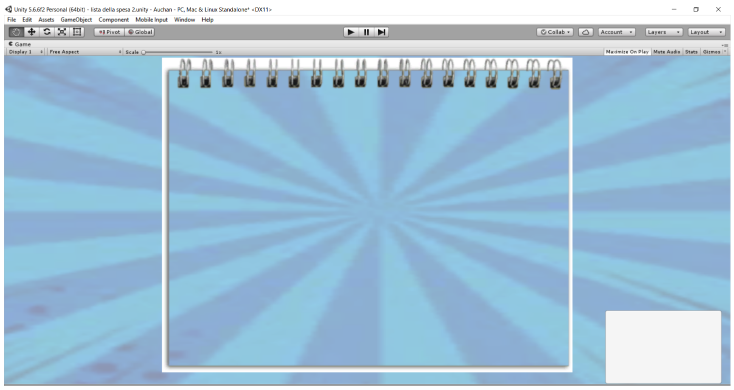

Figure A2.6: Screenshot of the baseline structure of scene *Shopping List*. The figure shows the 2D scene where the player can read all the products in the shopping list. At the bottom of the screen, there is a button to load the subsequent scene.

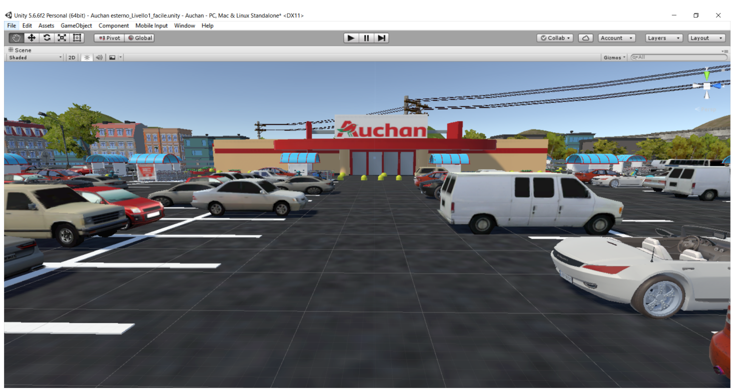

Figure A2.7: Screenshot of the first-person perspective in *ShopAut*. The image shows how the game is viewed when the player selects a first-person perspective. The body of the player-character is not visible and the player can control the game camera.

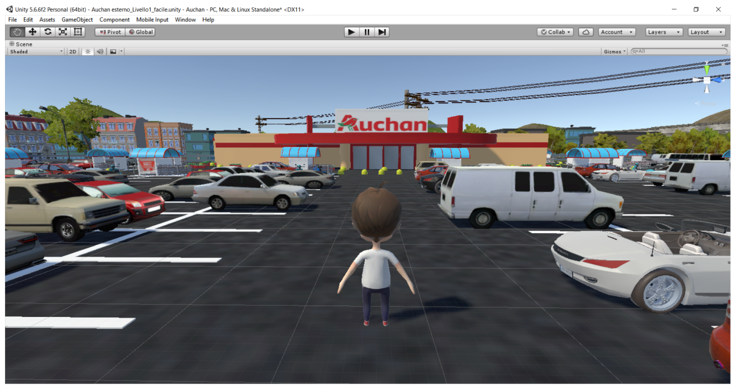

Figure A2.8: Screenshot of the third-person perspective in *ShopAut*. The image shows how the game is viewed when the player selects a third-person perspective. The player-character is a child, the main character of the game. The player does not control the game camera, which automatically follows the player character.

different body types, outfits, hairstyles, and physical attributes. Mixamo's technologies use machine learning methods to automate the steps of the character animation process. Overall, 35 characters were modelled; Figure A2.9 shows an example of the modelled characters.

A2.3 Development of the User Interface

As established in the design phase, the user interface has to be easy and intuitive, showing the game's mission, instructions feedback and dialogues. In particular, the game's mission is displayed through text and images, the game's instructions, feedback and dialogues are displayed through textual messages. Each UI element was inserted in a separate panel with a white background and a textual message and images (where planned); Figure A2.10 shows an example. The font of the textual messages - Starker Marker - was downloaded from Unity Asset Store (shorturl.at/hwlV6); blue was chosen as colour of the written messages.

A2.4 Development of the game dynamics

The behavior of the different "GameObjects" is controlled by specific components – "scripts" – attached to them. With scripts, new gameplay

Figure A2.9: An example of the modelled characters for *ShopAut*. The figure shows an example of modelled non-playable characters.

features and dynamics can be implemented. C# was used as a scripting language and MonoDevelop was chosen as an integrated development environment. Different specific scripts were implemented in order to create *ShopAut*'s dynamics. Overall, the implemented scripts were gathered into three groups:

1. Player-related scripts: all scripts implemented to develop the player dynamics.
2. UI-related scripts: all scripts implemented to manage the UI elements.
3. Game manager-related scripts: all scripts implemented to manage the main menu, scene loading, and the game score.

A2.5 Development of the Game Levels

For the implementation of the ten game levels, scenes were duplicated and modified based on the structure of each level, especially for their UI and scripts. This process facilitate the manage of the game on more levels and facilitate the development.

A2.6 Modelling of the Main Menu

After developing all the game levels, a main menu was created to manage the game options and the game itself. The design of the game menu

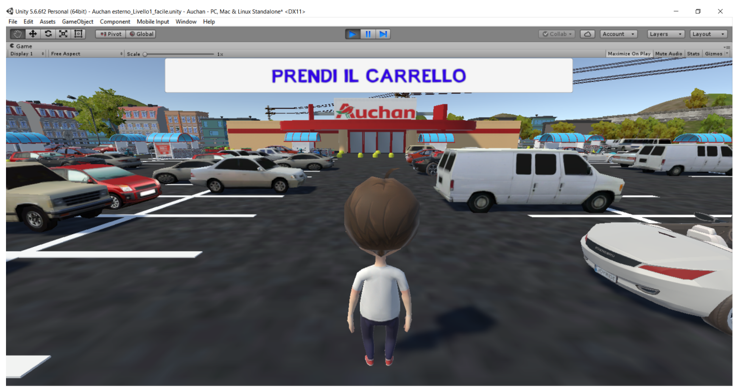

Figure A2.10: Example of an UI element (game instruction) in *ShopAut*.

followed the mockup in Figure A1.7, A1.8 and A1.9. Following the GDD instructions, the graphics are simple and clear and its structure was defined on the established options. An Unity asset (shorturl.at/oKRZ6) was chosen for the buttons style, as shown in Figure A2.11.

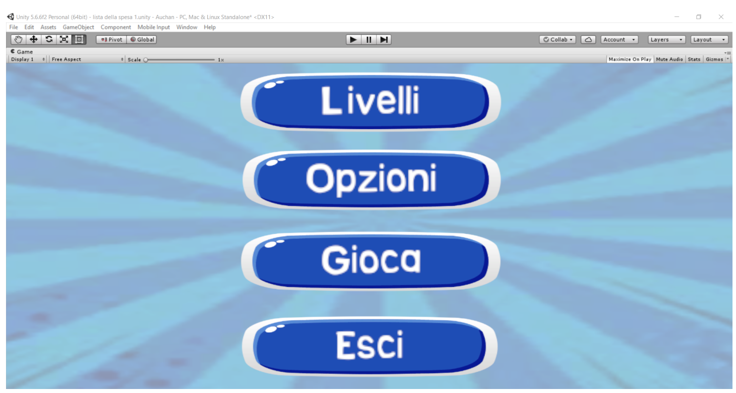

Figure A2.11: Screenshot of *ShopAut*'s main menu.

A2.7 Building

Game building was a continuous process, and for each new edit and integration a game build was published. This way, errors were immediately identified and a build of the game was made available based on the last good commit. Moreover, this process facilitated software testing performed by the testers and me. *ShopAut*'s build was published for PC.