Éberte Valter da Silva Freitas

A Socially Assistive Robot as a Therapeutic Tool for Applied Behavior Analysis Therapy in Children with Autism Spectrum Disorder Through Dynamically Modulated Serious Games

Vitória - Brazil

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PhD Thesis presented to the Postgraduate Program in Electrical Engineering, Federal University of Espirito Santo, in partial fulfillment of the requirements for the degree of Doctor in Electrical Engineering

Federal University of Espirito Santo

Postgraduate Program in Electrical Engineering

Orientador: Teodiano Freire Bastos-Filho

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Ficha catalográfica disponibilizada pelo Sistema Integrado de Bibliotecas - SIBI/UFES e elaborada pelo autor

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F862s

Freitas, Éberte Valter da Silva, 1993-
A Socially Assistive Robot as a Therapeutic Tool for Applied Behavior Analysis Therapy in Children with Autism Spectrum Disorder Through Dynamically Modulated Serious Games / Éberte Valter da Silva Freitas. - 2024.
163 p.

Orientador: Teodiano Freire Bastos-Filho.
Tese (Doutorado em Engenharia Elétrica) - Universidade Federal do Espírito Santo, Centro Tecnológico.

1. Socially Assistive Robot. 2. Serious Games. 3. Dynamic Modulation of Difficulty. 4. Autism Spectrum Disorder. I. Bastos-Filho, Teodiano Freire. II. Universidade Federal do Espírito Santo. Centro Tecnológico. III. Título.

CDU: 621.3

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In memoriam
to my dear cousin,
Philipe Villeneuve Oliveira
Rego.

"Amar. E basta."

Acknowledgements

I am grateful to my family. Everything I am is thanks to you and for you. This research has given me a deeper understanding of the needs and possibilities my nephew will have throughout his life, and now I feel stronger and more prepared to support him and take even better care of all of you.

I am immensely grateful to my advisors, Professor Teodiano Freire Bastos Filho and Professor Eliete Maria de Oliveira Caldeira, for their teachings, knowledge, support, sensitivity, and the opportunities they have provided. Your professional and human conduct, shown in various moments, is an inspiration I carry with me and a model to follow. I am especially thankful to Professor Eliete, whose messages, in moments of distress, brought me peace and confidence to move forward.

Over these four years, I have built a support network formed by special people who listened to me, supported me, and contributed to this achievement. With affection, I record the names of some of them: Jeferson Carvalho, Luann Queiroz, Rodrigo Louzada, Josiany Souza, Marcelo Medeiros, Marcelo Mendes, João Panceri, Sheila Schreider, Letícia Silva, Mateus Benezoli, and Isabel Miranda. My heartfelt thanks to all of you.

Finally, I am grateful for life and its unexpected turns. In 2019, while searching for Ph.D. programs in biomedical engineering, I came across a news article on the G1 website about my future advisor's lab, which led me to this path. Since then, I have experienced incredible moments, met wonderful people, and fallen in love with this city. Despite its challenges, life continues to surprise me in ways for which I am profoundly grateful today.

Abstract

This work presents the programming/adaptation of the Socially Assistive Robot (SAR) called Mobile Autonomous Robot for Interaction with Autistics and Trisomy 21 (MARIA T21) to be able to carry out interventions, according to the Applied Behavior Analysis (ABA) therapy, applied to Children with Autism Spectrum Disorder (ASD), Serious Games (SGs), which are projected by MARIA T21, with difficulty modulation dynamics, are used as part of this therapy thus creating a motivating and facilitating effect for children and therapists. The SGs were developed in Unity 3D, using C Sharp language (C#), and modulated according to the child's performance, eye attention level, and user's facial emotion, being integrated into the robot through the Robot Operating System (ROS). The child-Robot Interaction (CRI) protocol followed in this research was carried out in a child's psychotherapy room at the APAE (Association of Parents and Friends of Excepcional People for the acronym in Portuguese) of Vitoria in Espirito Santo state (Brazil), which was instrumented with four video cameras and supervised by a group of researchers. The sample consisted of 18 children with a conclusive diagnosis of ASD, 3 girls and 15 boys, aged 5 to 9 years and presence of stereotyped movements of eyes and/or hands and/or feet. The experiments were separated into three modules for which SGs or specific therapeutic dynamics were applied, namely: Cognitive Module, Physical Module and Functional Module. The first one brings together the games and dynamics applied by MARIA T21 focused on the development and improvement of cognitive learning skills, whereas the physical module brings SGs for motor evaluation and correction, that can be used for physical and postural strengthening by a physiotherapist. Finally, the functional module has applications of SGs and Occupational Therapy dynamics in order to work on the so-called Activities of Daily Living (ADLs) and encourage autonomy in those assisted. In addition to the data recorded by MARIA T21, two evaluation scales – Pediatric Evaluation of Disability Inventory Computer Adaptive Test (PEDI-CAT) and System Usability Scale (SUS) – were applied for each module, and another for the degree of acceptance of the robot in therapy by the child. The results obtained so far enable the use MARIA T21 as an ABA therapeutic tool. In addition, the SGs are capable of dynamically modulating their difficulty, providing greater user adherence and continued attention in the optimal learning zone of the ABA bibliography while carrying out the activities. The technology embedded in the robot has also enabled the identification and quantification of characteristics and parameters, such as the presence and recurrence of stereotypies and postural dysregulations, placing the robot as an innovative and promising tool to assist health professionals in the early diagnosis, conduction and follow-up of therapies.

Key-words: SAR; Serious Games; Dynamic Modulation of Difficulty; ASD.

Resumo

Este trabalho apresenta a programação/adaptação do Robô Socialmente Assistivo (RSA) chamado Robô Autônomo Móvel para Interação com Autistas e Trissomia 21 (MARIA T21) para realizar intervenções de acordo com a terapia de Análise do Comportamento Aplicada (ABA), aplicada a crianças com Transtorno do Espectro Autista (TEA). Jogos sérios (JSs), projetados pelo MARIA T21 com dinâmicas de modulação de dificuldade, são utilizados como parte dessa terapia, criando assim um efeito motivador e facilitador para as crianças e terapeutas. Os JSs foram desenvolvidos no Unity 3D, usando a linguagem C Sharp (C#), e modulados de acordo com o desempenho da criança, nível de atenção ocular e emoção facial do usuário, sendo integrados ao robô através do Sistema Operacional de Robôs (ROS). O protocolo de Interação Criança-Robô (CRI) seguido nesta pesquisa foi realizado em uma sala de psicoterapia infantil na APAE (Associação de Pais e Amigos dos Excepcionais) de Vitória, no estado do Espírito Santo (Brasil), equipada com quatro câmeras de vídeo e supervisionada por um grupo de pesquisadores. A amostra consistiu em 18 crianças com diagnóstico conclusivo de TEA, sendo 3 meninas e 15 meninos, com idades entre 5 e 9 anos, e presença de movimentos estereotipados dos olhos e/ou mãos e/ou pés. Os experimentos foram divididos em três módulos, nos quais JSs ou dinâmicas terapêuticas específicas foram aplicadas, a saber: Módulo Cognitivo, Módulo Físico e Módulo Funcional. O primeiro reúne os jogos e dinâmicas aplicados pelo MARIA T21 focados no desenvolvimento e aprimoramento de habilidades de aprendizagem cognitiva, enquanto o módulo físico traz JSs para avaliação e correção motora, que podem ser usados para fortalecimento físico e postural por um fisioterapeuta. Por fim, o módulo funcional tem aplicações de JSs e dinâmicas de Terapia Ocupacional para trabalhar as chamadas Atividades de Vida Diária (AVDs) e incentivar a autonomia dos assistidos. Além dos dados registrados pelo MARIA T21, duas escalas de avaliação — o Teste Adaptativo de Inventário Pediátrico de Avaliação de Deficiência (PEDI-CAT) e a Escala de Usabilidade de Sistemas (SUS) — foram aplicadas para cada módulo, assim como outra para avaliar o grau de aceitação do robô na terapia pela criança. Os resultados obtidos até o momento viabilizam o uso do MARIA T21 como uma ferramenta terapêutica ABA. Além disso, os JSs são capazes de modular dinamicamente sua dificuldade, proporcionando maior adesão do usuário e manutenção da atenção na zona de aprendizado ideal da bibliografia ABA durante a realização das atividades. A tecnologia embarcada no robô também permitiu a identificação e quantificação de características e parâmetros, como a presença e recorrência de estereotipias e desregulações posturais, posicionando o robô como uma ferramenta inovadora e promissora para auxiliar profissionais de saúde no diagnóstico precoce, condução e acompanhamento de terapias.

Palavas-chave: Robô Socialmente Assistivo; Jogos Sérios; Modulação Dinâmica de Dificuldade; Transtorno do Espectro Autista.

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List of Abbreviations and Acronyms

ABC	Antecedents, Behavior, and Consequences
ADHD	Attention Deficit Hyperactivity Disorder
ADLs	Activities of Daily Living
APAE	Association of Parents and Friends of Exceptional People
AMAES	Association of Friends of Autistic Individuals of Espírito Santo
ASD	Autism Spectrum Disorder
EIBI	Early Intensive Behavioral Intervention
EVA	Ethylene Vinyl Acetate
ICF	Informed Consent Form
IEPs	Individualized Education Programs
IoT	Internet of Things
LIDAR	Light Detection And Ranging
MARIA T21	Mobile Autonomous Robot for Interaction with Autistics and Trisomy 21
PEDI-CAT	Pediatric Evaluation of Disability Inventory Computer Adaptive Test
PECS	Picture Exchange Communication System
PRT	Pivotal Response Training
RBSR	Repetitive Behavior Scale-Revised
ROS	Robot Operating System
SARs	Socially Assistive Robots
SG	Serious Game
SUS	System Usability Scale
T21	Trisomy 21 Chromosome

TAC	The Cancellation Attention Test
TMT	Trail Making Test
TW	Toe Walking
UK	United Kingdom
US	United States
VR	Virtual Reality
VBI	Verbal Behavior Intervention
DDA	Dynamic Difficulty Adjustment
DSM-5	Diagnostic and Statistical Manual of Mental Disorders - 5th Edition
DTT	Discrete Trial Training
HF	Hand Flapping
GAS	Goal Attainment Scaling
OpenCv	Open Source Computer Vision Library

Summary

1 Introduction

The increase in the number of people diagnosed with Autism Spectrum Disorder (ASD) and the need for lifelong support in areas such as education, health, and community services make ASD a significant social concern with financial impacts on this group of people, their families, public and private health systems, state financial aid programs, and society as a whole (ROGGE; JANSSEN, 2019).

Although early detection and therapy of ASD is important, there is still much uncertainty. Basic questions regarding diagnostic stability in childhood, overlapping symptoms with other disorders, such as language delay or global development, still need to be answered. In addition, monitoring the evolution of therapies is challenging (PIERCE et al., 2019).

Socially Assistive Robots (SARs) are an emerging technology that has expanded the assessment and intervention for children with ASD. SAR refers to a robot that provides assistance to the user in social environments (CHO; AHN, 2016; HYDE et al., 2019). These robotic systems can improve the screening, diagnosis, and therapeutic follow-up process, allowing for personalized and continuous sessions. SAR can also collect and analyze data from interactions with the user, becoming a valuable tool for therapists to monitor patients' progress and facilitate diagnosis (MARTINEZ-MARTIN; ESCALONA; CAZORLA, 2020).

For SAR to be effective in treating individuals with ASD in real-world settings, it is necessary to follow evidence-based practices established by therapists. Applied Behavior Analysis (ABA) is the most widely used method worldwide for ASD interventions, which involves the systematic use of learning theory-based interventions to improve socially significant behaviors (MATSON et al., 2012; SHAMSUDDIN et al., 2015; HYMAN et al., 2020).

In the United States (US), Individualized Education Programs (IEPs) dictate that children with behavioral problems requiring alternative educational placements must receive ABA. However, many regions lack qualified ABA analysts, resulting in a lack of adequate care for many children (DICKSTEIN-FISCHER; FISCHER, 2014). The average annual cost for individual intensive ABA services is estimated between US$46,000 and US$100,000 (DICKSTEIN-FISCHER et al., 2018; SONGBIRD, 2022). In Brazil, ABA is the only therapeutic intervention methodology for ASD covered by the national health system (Unified Health System called SUS for the acronym in Portuguese) (GAIATO, 2018).

There are several types of ABA instruction, including Verbal Behavior Intervention (VBI) (CASPERSON, 2023), Early Intensive Behavioral Intervention (EIBI) (MOUNZER et al., 2023), Discrete Trial Training (DTT) (KATES-MCELRATH; AXELROD, 2006), and Pivotal Response Training (PRT) (LEI; VENTOLA, 2017), also known as naturalistic ABA. Each type varies in terms of teaching method.

DTT is a widely used technique by behavioral analysis professionals. It uses successive reinforcements, stimuli, and corrections to teach specific behaviors. Meanwhile, PRT values the child's motivation and joy during the learning process (KOEGEL et al., 2019).

Recently, there have been evaluations of the use of SAR in DTT-based therapies due to their predictable and programmable structure (BEGUM et al., 2015; WARREN et al., 2015; SALVADOR et al., 2016; FENG et al., 2018). However, to date, there are no studies involving the use of SAR in PRT-based therapies, as these therapies require customized protocols that are constantly re-evaluated and are based on complex variables, such as the subject's attention, interest and cognitive level (KOEGEL et al., 2019).

This study presents the development and application of Serious Games (SGs) for therapy assisted by the Mobile Autonomous Robot for Interaction with Autistics and Trisomy 21 (MARIA T21), which aims to demonstrate the feasibility and efficacy of this approach. SGs are games designed with specific objectives beyond entertainment, such as training, education, social awareness, business simulation, among others (STEINER et al., 2015). These games use interactive technology and game elements, such as characters, narratives, rewards, and challenges, to achieve their goals in a fun and effective manner (ASLAN S.; BALCI, 2015; SANTOS C.; SOUZA J.; VALTUIR; LANZA, 2017).

The developed research SGs have dynamic difficulty adjustments, based on each subject unique learning patterns, whose therapeutic goals are focused on three areas: cognitive, physical and motor improvement, and functionality. In this way, MARIA T21 acts as a therapeutic tool in accordance with the principles of the ABA methodology, both of the DTT and PRT type.

This research was authorized by the UFES's Ethics Council under protocol number 1.121.638. The experiments were carried out at the Association of Friends of Autistic People of Espírito Santo (in Portuguese AMAES) in Vitória and the Association of Parents and Friends of Exceptional People (APAE for the acronym in Portuguese) in Vila Vela and Vitória, Espirito Santo state, Brazil, according to the partnership established between UFES and these institutions.

1.1 Motivation

SAR can help enhance children with ASD and support therapists in diagnosing and delivering rehabilitation therapies more efficiently. This can also help reduce occupational burnout (DICKSTEIN-FISCHER et al., 2018; ROGGE; JANSSEN, 2019; KHODATARS et al., 2021).

Although there is currently no known cure for ASD (as it not a disease), it is important to continue working to minimize costs without compromising interventions (DICKSTEIN-FISCHER; FISCHER, 2014). Customization with technology is a major challenge, as SARs must adapt to the unique needs of each child with ASD (CLABAUGH et al., 2019).

Most of the research on SARs and ASD so far has focused on the quality of the interaction between children and robots (CHO; AHN, 2016). This makes it difficult to obtain applicable conclusions about SAR-based therapy for children with ASD. Additionally, most previous studies have focused on social skills, leaving gaps in physical and functional training and without using evidence-based therapeutic methodologies such as ABA (DICKSTEIN-FISCHER et al., 2018; CLABAUGH et al., 2019).

In addition to helping reduce the overall costs of ABA therapy, SARs also make this therapy more affordable for low-income families by reducing costs and time for healthcare professionals. For example, the educational SAR NAO costs US$12,990 and the online course for controllers costs US$1,490 (INBAR, 2023), while the educational SAR Milo costs US$6,500 (with three years warranty) and US$3,500 application fee for full training (INBAR, 2018). This is a significant reduction compared to the estimated costs per year for ABA (SONGBIRD, 2022) services. Thus, it is important to develop a robust, evidence-based behavioral analysis design to fully reap the benefits of SARs using ABA.

To enhance ASD therapies, it is necessary collaboration between behavior analysts and robotic engineers. This will ensure that SAR projects are integrated into conceptual approaches to ASD therapy, considering relevant design and engineering issues (DICKSTEIN-FISCHER et al., 2018). It is worth commenting that robotics is becoming increasingly common, which is important to integrate it into ABA to advance ASD therapy, including cost, quality, and access issues.

Current barriers to access therapy include the limited number of qualified professionals, high administrative burden, ABA therapist burnout rates, and high costs (CHO; AHN, 2016; DICKSTEIN-FISCHER et al., 2018). In addition, there is no effective way to confirm ASD diagnosis and monitor the evolution of interventions through exams. For this reason, it is necessary an objective assessment of social function of children with ASD, and there is an expectation by researchers that hope SARs can help achieve this goal (CHO; AHN, 2016;

HYDE et al., 2019).

Customized therapies and learnings are an excellent way to improve the development of and motivation for research, especially for children with ASD. However, the time and financial resources required make these services inaccessible to many, creating an opportunity for support from SARs (CLABAUGH et al., 2019).

There is still limited knowledge about motor deficits (timing and organization, muscle tone, balance, and gait) in children with ASD, and how to develop these skills. Moreover, distinguishing complex tics from stereotyped movements can be a challenge (LICARI et al., 2020). Another important factor is that in children with ASD the functional impairment associated with motor difficulties has a significant impact on functional activity and persists throughout life (HYMAN et al., 2020). Considering the good results obtained with SGs in the development of physical abilities in physical therapies for people with other disabilities, this research proposes the use of SGs in physiotherapeutic activities as a way of training motor skills in children with ASD and their application through SARs.

1.2 Hypothesis

The following hypotheses were established in this research:

1. Can SAR be used as an effective tool to increase engagement by children with ASD during ABA therapy utilizing PRT methodology through dynamically modulated SGs based on user performance and guidance and reinforcement according to the DTT type, with cognitive, physical, and functional emphasis?
2. Is Dynamic Difficulty Adjustment (DDA) of SGs capable of meeting the demand for personalized therapy needs for children with ASD, keeping them in an optimal state of learning for longer periods of time?

In other words, the main hypothesis of the research is whether the social robot MARIA T21 is capable of applying ABA methodology according to DTT principles through challenges, guidance, and reinforcement, and also pioneeringly PRT through SGs that, when presenting DDA, maintain the children with ASD in the optimal state of balance between challenge and comfort, leading to promotion of learning new abilities.

1.3 Research Aims and Objectives

The overall objective of this study is to develop a strategy that enables the SAR MARIA T21 to apply the scientifically recognized and most widely used therapeutic methodology currently available (the ABA methodology). This will be accomplished by implementing SGs that adapt to the individual learning pace of the child, providing stimulation without causing disinterest due to a lack of challenge or overwhelming frustration from excessive challenge, following the principles of PRT. Additionally, the system incorporates visual and auditory feedback for reinforcement and correction, following the principles of DTT.

To achieve this, the following sub-objectives were defined.

1. Development of control strategies for the robot;
2. Development of SGs;
3. Development of dynamic modulation strategies for the SGs;
4. Conducting experiments for validation of the systems and methodology.

1.4 Contributions of this Research

The combination of ABA with technology in the form of SAR is an important way of overcoming obstacles to obtain effective ABA interventions, such as accessibility, administrative burdens for therapists, and high rates of therapist burnout. This research shows that collecting information about how children with different characteristics, such as cognition, language, social engagement, stereotypical and abnormal sensory behaviors, are affected by SAR therapeutic programs allow for a clearer evaluation of where these programs can be used most effectively and reduce potential errors in diagnostic assessment and progress based solely on behavioral observation.

Additionally, this research shows that a SAR system that can apply PRT techniques keeps children motivated and interested in the goal of the SGs. In addition, modulation addresses individual needs for instruction and challenge over time to ensure each child's proficiency while maintaining their interest without excessive frustration. This research addresses the domains of cognitive, physical, and functional learning together, in an intervention specifically designed for children with ASD. It is believed that the results of this research will spark interest among clients, therapists, scientists, and the general public.

1.5 Structure of the Thesis

This Doctoral Thesis proposal consists of seven chapters. In the Introduction, the motivation that led to the work developed is introduced, as well as the hypotheses, the purposes and objectives of the research, and the contributions of this research.

- Chapter 2 describes the research history, presenting a literature review on some of the guiding themes.

- Chapter 3 presents the SAR employed in the study, which is the robot MARIA T21.
- Chapter 4 presents the foundation and description of the development of the SGs applied by MARIA T21.
- Chapter 5 details the established experimental protocol, presenting the profile of the participants, scenario, procedure, and external evaluation scale employed.
- Chapter 6 presents results of this research, as well as a discussion of the results obtained.
- Chapter 7 presents the conclusions, limitations and future works of this research.

2 Research Background

2.1 Autism Spectrum Disorder (ASD)

ASD is a neurobiological condition that affects brain development and manifests through difficulties in social interaction, communication, and repetitive behaviors. Genetic and environmental factors are responsible for its occurrence (MATSON et al., 2012; HODGES; FEALKO; SOARES, 2020; HYMAN et al., 2020). Additionally, ASD is linked to other conditions such as epilepsy, Attention Deficit Hyperactivity Disorder (ADHD), concentration problems, gut issues, opposition, anxiety, depression, eating disorders, and sleep disturbances (ROGGE; JANSSEN, 2019; OMAR et al., 2019).

Regarding social interaction and communication, individuals with ASD may exhibit inappropriate laughter, insensitivity to pain, difficulty with eye contact, sensitivity to sound, food selectivity, reluctance to hug, difficulty in recognizing and expressing emotions, echolalia, among others (RAJ; MASOOD, 2020).

The prevalence of ASD can vary depending on the country, period, and study method, but there has been a considerable increase in recent decades (ROGGE; JANSSEN, 2019). In the United States(US), the prevalence of ASD increased from 2.24% in 2014 to 3.49% in 2020, and according to the Centers for Disease Control and Prevention (CDC) currently it is 1 in every 36 children (PIERCE et al., 2019; HODGES; FEALKO; SOARES, 2020; MAENNER et al., 2021; LI et al., 2022). In the United Kingdom (UK), one in every 64 children has ASD (SHAMSUDDIN et al., 2015). In Asian countries, the number of cases has also increased, but the prevalence is lower compared to Western countries, with prevalence in Eastern Asia at 0.51%, Western Asia at 0.35%, and the South at 0.31% (QIU et al., 2020). Unfortunately, there is no information available on the prevalence of ASD in Brazil, but considering the number of brazilian children up to 12 years old is 35.5 million (IBGE, 2018), when applying CDC results, it is possible to have an estimate of more than 800,000 autistic child in Brazil.

Individuals with ASD and their families face higher costs, including expenses for healthcare and medical services, therapy, special education, loss of income for adults with ASD, informal caregiving, and loss of productivity for caregivers and family members, as well as necessary accommodations (ROGGE; JANSSEN, 2019; HYMAN et al., 2020). Despite growing awareness of coordination difficulties among individuals with ASD and the inclusion of catatonia as a possible co-occurring condition in the Diagnostic and Statistical Manual of Mental Disorders - 5th Edition (DSM-5), motor impairment is not yet included in the diagnostic criteria for ASD (HYMAN et al., 2020). Recent studies indicate that motor difficulties can be seen in 50 to 79% of individuals with ASD, almost at the same level as clinical markers of intellectual and linguistic disabilities (LICARI et al., 2020). Furthermore, these difficulties tend to be more prevalent in cases with restrictive, repetitive, and non-verbal behaviors, and tend to increase with increasing diagnostic age.

Early identification and use of therapy can improve the quality of life for children with ASD and their families, but there is still a significant need for early detection, intervention, and services (QIU et al., 2020; KRITHIGA, 2019). Although measures have been taken in recent years to reduce the age of ASD diagnosis, the global average age at diagnosis is 60.48 months (range: 30.90–234.57 months), reducing to 43.18 months (range: 30.90–74.70 months) when considering only children under 10 years of age (HOF et al., 2021). This late detection age is a missed opportunity due to the rapid pace of brain development that occurs between birth and 3 to 4 years of age (PIERCE et al., 2019).

Since the spectrum of autism symptoms is vast, due to the diversity of types and intensity that each person with ASD faces, it is important that they receive personalized therapies that address their different problems (KRITHIGA, 2019). Furthermore, there is a need for continuous efforts to recognize and diagnose ASD in a universal and standardized manner in prevention and control programs, in order to increase the success of therapeutic interventions and evaluate the financial and health impact of the condition. This will ensure that children and adults with ASD and their families have access to adequate funding and the services they need (QIU et al., 2020; HOF et al., 2021; CHIAROTTI; VENEROSI, 2020).

2.2 Applied Behavior Analysis (ABA)

ABA, also known as the Lovaas Model, is the most widely used evidence-based method for addressing social and communication deficits, as well as reducing challenging behaviors such as stereotypes (COOPER et al., 2007; SHAMSUDDIN et al., 2015). ABA is used to teach social skills, play skills, group instruction, and academic behaviors, as well as Activities of Daily Living (ADLs).

Ivar Lovaas was a pioneer in ABA interventions to improve severe challenging behaviors and establish communication. His studies showed that children who received intensive early ABA had significant development gains compared to those who received it later (SMITH; EIKESETH, 2011). The more hours of ABA, the greater the development outcomes (MATSON et al., 2012; HYMAN et al., 2020).

Lovaas proposed several ways to improve results, including positive reinforcement, parent involvement, and increased therapy hours per week. For effective results, it is now understood that ABA therapy should begin during early childhood, from 1.5 to 6 years, with 20 to 40 hours per week of individual instruction with a professionally trained ABA therapist (LOUIE et al., 2021).

In the US, Individualized Education Programs (IEPs) mandate that children with behavior problems that result in alternative educational placements must receive ABA. Unfortunately, many areas have a shortage of qualified ABA analysts, resulting in children not receiving adequate and timely services (DICKSTEIN-FISCHER; FISCHER, 2014). The average cost for intensive ABA services varies from US$46,000 to US$100,000 per year (DICKSTEIN-FISCHER et al., 2018; SONGBIRD, 2022). In Brazil, ABA therapy is covered by the national health system as the only therapeutic intervention methodology for ASD (GAIATO, 2018).

Worldwide, ABA is a well-known intervention to help children with special needs, especially those with ASD and intellectual delay (DICKSTEIN-FISCHER; FISCHER, 2014). It uses a behavior modification approach, dividing the target behavior into simple and repetitive tasks that are presented sequentially. During therapy, the child's performance is measured and analyzed. As human brain has plasticity, ABA allows children with ASD to learn new skills and unlearn inappropriate behaviors (SHAMSUDDIN et al., 2015; MARTINEZ-MARTIN; ESCALONA; CAZORLA, 2020). The study of ABA has a long history and has produced the most promising results among research methods to date (MATSON et al., 2012; DICKSTEIN-FISCHER et al., 2018).

Language and general communication are common concerns, and the Picture Exchange Communication System (PECS) is a highly effective behavior-based communication method. As for challenging behaviors, aggression, stereotyping and self-injury are the most common, although this is not a trend in ASD research (MATSON et al., 2012).

Instruction in ABA uses an Antecedent-Behavior-Consequence (ABC) model (COOPER et al., 2007). Antecedent refers to the environmental and social factors that occur before a desired target behavior. Behavior is the person's response to the antecedent. Consequence is what happens immediately after the behavior, including compliments, rewards, warnings or error corrections (LOUIE et al., 2021). For example, an antecedent may be a greeting from a robot to a child with ASD during a meeting. The behavior is whether the child responds with a greeting to the robot. The consequence is the robot providing compliments, stimuli or rewards to the child for a desired behavior.

Since the deficits are unique to each individual, the procedure used in ABA clinical practice is individual and personalized, and includes (DOUNAVI, 2017):

1. Assessment of deficits and excesses;
2. Implementation of a customized intervention plan;
3. Continuous frequent reassessment of the intervention.

There are several types of ABA instruction, which vary depending on the teaching approach. ABA Verbal Behavior Intervention focuses solely on the teaching of verbal skills, while ABA Early Intensive Behavioral Intervention is often applied to children under three years of age. Other types include DTT and PRT, also known as naturalistic ABA.

DTT is a crucial technique used by applied behavior analysis professionals, developed by Ivar Lovaas at the University of California, Santa Barbara (USA). It uses direct commands and reinforcement to create clear contingencies and shape new skills (SMITH; EIKESETH, 2011; LOUIE et al., 2021). Lessons are broken down into simple parts, and positive reinforcement is used to reward correct responses and behaviors, correcting and encouraging new efforts in case of error (DICKSTEIN-FISCHER et al., 2018). Although it is the most commonly used strategy in ABA, it is criticized for not working ideally in pediatric clinical practice.

PRT is a behavioral therapy developed by Lynn and Robert Koegel of the University of California, Santa Barbara (USA), that prioritizes the child's motivation and joy while learning (KOEGEL et al., 2019). In ABA PRT, lessons are inserted into the child's ADLs, which can increase the child's interest in following the goals. According to naturalistic ABA, the child functions in three zones: the comfort zone, where the child does only what he/she wants and knows, reproducing what he/she already knows and not learning anything new; the learning zone, where there is stimulation that generates a response and is the moment when the child is expanding his/her repertoire and acquiring new knowledge; and the dysregulation zone, when the intervention is too invasive, too boring or the child has no motivation to do it, and there is no learning. The ideal intervention alternates between the comfort zone and the learning zone (GAIATO, 2018).

It is a fact that intensive individual health care can be limiting the number of people professionals can positively impact, and assessment of progress is often based on observations. Thus, SARs can be a useful tool for these professionals, as a robot may offer untired interventions for people with ASD (LOUIE et al., 2021).

In 2015, Begum et al. (2015) used DTT with the humanoid robot NAO to teach appropriate social behaviors to adolescents with ASD. The robot greeted the person with ASD and gave him/her the opportunity to answer correctly. If the person still couldn't respond, the robot would give a verbal instruction. The effectiveness of the intervention was evaluated with three adolescents with ASD who already had the ability to initiate and respond to social greetings, but only one of them was able to respond to the greeting without prompts.

In 2016, Salvador et al. (2016) used the robot Zeno for a DTT-based emotion recognition intervention for children and adolescents with ASD. The robot played three different games to recognize emotions, and correct responses were reinforced with social praise. For wrong answers, a protocol was used that started with few verbal cues and increased the number of cues over time. However, their study with two children with ASD in three intervention sessions did not show significant improvements in the children's ability to recognize emotions.

In 2018, Feng et al. (2018) used the robot NAO in DTT format therapy sessions to help children with ASD imitate gestures. The robot presented a gesture to the child, asking him/her to copy it. If the child copied correctly, he/she was praised. If not, the robot showed how to do it correctly and asked the child to try again. A study with two children showed that the robot can facilitate imitation therapy, but the effectiveness of the intervention was not been evaluated.

In 2021, Louie et al. (2021) used the robot NAO to teach children with ASD how to answer questions. The DTT-based intervention was successful and the children improved on the skill taught by the robot and enjoyed interacting with it.

In general, robot-mediated interventions have had a positive impact on the behavior of people with ASD. However, integrating this technology into actual therapies is still difficult, as they currently do not follow ABA standards for children with ASD.

Unless other methods are developed that are more effective than ABA, the conclusion that ABA is the most effective therapy for ASD should be maintained (MATSON et al., 2012). So, developing robotic systems that apply ABA to children with ASD is still an important task.

2.3 Socially Assistive Robot (SAR)

In recent years, robots have been widely used to assist people with disabilities and special needs in rehabilitation (SHAMSUDDIN et al., 2015). SAR is a type of robot that combines robotics and computing to provide personalized, socially situated, and co-present interventions (FEIL-SEIFER; MATARIĆ, 2011; MARTINEZ-MARTIN; ESCALONA; CAZORLA, 2020). These robots are capable of realize a variety of interactions that can be executed with or without the help of a professional, providing education and feedback to the user (CHO; AHN, 2016).

Children with ASD are attracted to technology and inanimate objects and may feel more comfortable interacting with robots because their behavior and reactions are more predictable and consistent than humans (SHAMSUDDIN et al., 2015; DICKSTEIN-FISCHER et al., 2018; MARTINEZ-MARTIN; ESCALONA; CAZORLA, 2020).

However, interventions with the robot need to be adapted to the needs and preferences of children with ASD, thus, robot-based solutions are ideal for being specific, repetitive, motivating, and customizable (SHAMSUDDIN et al., 2015; CLABAUGH et al., 2019). Adittionally, this involves the concept of interdisciplinarity, which is necessary to combine research in artificial intelligence, human-robot interaction, and machine learning (MARTINEZ-MARTIN; ESCALONA; CAZORLA, 2020).

In the United States, the average life cost to support a person with ASD and intellectual disability is US$2.4 million, and can be even higher depending on the severity of the diagnosis and the intensity of the required intervention (DICKSTEIN-FISCHER et al., 2018). Additionally, therapists also face professional burnout and deviation from procedures due to the intensive nature of the work. To address these challenges, SARs should be developed with autonomy to perform the required therapies. SARs can be used to administer sessions, collect data, recognize repetitive behaviors, increase joint attention, analyze interactions, and generate reports and charts. SARs are therefore a valuable resource for ABA therapists (CHO; AHN, 2016; DICKSTEIN-FISCHER et al., 2018).

Robotic systems with therapeutic value for children with ASD have been well introduced in the robotics community (KRITHIGA, 2019). Table 1 lists some of the SARs employed as therapeutic tools for children with ASD.

Table 1 – Robots used in autism therapies

Robot/Publication	**Appearance**	**Description**
Kiwi (PAKKAR et al., 2019)		Primarily designed for children with ASD, it is used together with a tablet that motivates the child to learn social skills.

Continues on the next page

Tabela 1 – *Table continuation*

Robot/Publication	**Appearance**	**Description**
NAO (SHAMSUDDIN et al., 2011)		Autonomous humanoid capable of interacting with children with ASD, performing verbal and non-verbal interactions, making eye contact, imitation skills, reacting appropriately to the behavior of others, and generating attention.
Keepon (KOZIMA; MICHALOWSKI; NAKAGAWA, 2009)		Designed for simple, natural, non-verbal interaction with children with ASD.
Pleo (MOERMAN; JANSENS, 2021)		Interactive, it makes use of similarity with domestic animals to better maintain interest and engagement over time, and positively affects the well-being of hospitalized children.
Milo (FREITAS et al., 2017)		It can walk, talk, and model facial expressions. Offers verbal lessons to teach social behavior and emotional aspects.

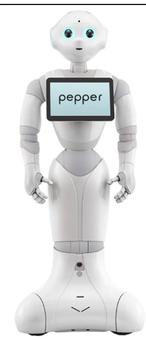
Continues on the next page

Tabela 1 – *Table continuation*

Robot/Publication	**Appearance**	**Description**
Tito (DUQUETTE; MICHAUD; MERCIER, 2008)		Mediator robot to stimulate attention in children.
Kaspar (DAUTENHAHN et al., 2009)		It can imitate everyday actions such as eating, waving hands. It can also play music and verbally train the child to have proper eye contact and teach lessons about normal human behavior.
Popchilla (DUNST et al., 2013)		Used to promote affective behavior and vocalizations in children.
Cosmobot (BRISBEN et al., 2005)		Provides motivation for children with cerebral palsy during upper limb therapy sessions.

Continues on the next page

Tabela 1 – *Table continuation*

Robot/Publication	**Appearance**	**Description**
Pepper (KARAR et al., 2019)		It has a touch sensor and is capable of identifying multiple variations in the human voice. Employed in vertical communication studies with people with ASD.
Pabi (DICKSTEIN-FISCHER; FISCHER, 2014)		It aims to improve early diagnosis and intervention for children with ASD.
i-Sobot (WATANABE; YONEDA, 2009)		It was not developed as a SAR but its use facilitates the "praxis by imitation" of children with ASD for a series of gross motor actions based on karate and dance.
Ifbot (KATO et al., 2004)		It can communicate with humans through happy conversations and emotional facial expressions.

Continues on the next page

Tabela 1 – *Table continuation*

Robot/Publication	**Appearance**	**Description**
Robota (BILLARD et al., 2007)		Imitator robot to assess children's imitation ability and teach children simple coordinated behaviors.
Paro (WADA et al., 2010)		Similar to a baby seal, it may be effective in reducing stress in nursing home residents and produce greater social activity among residents.
Alyx (AYLETT et al., 2018)		Developed primarily for autistic adults to train in relation to emotions and simple everyday actions such as handshaking.
N-MARIA (PIERO et al., 2019)		It simulates facial expressions considering proxemics information to increase interaction between it and children with ASD.

End of table

Artificial intelligence techniques and SARs have a positive impact not only on children with ASD, but also on their parents, therapists, and caregivers (MARTINEZ-MARTIN; ESCALONA; CAZORLA, 2020; FEIL-SEIFER; MATARIĆ, 2011). In addition to facilitating access to therapy, SARs can also help reduce monotony and workload for therapists by providing continuous assessments (CHO; AHN, 2016; DICKSTEIN-FISCHER et al., 2018). However, to ensure that these tools are effective, it is important to include them in treatment efficacy studies to verify if there are specific benefits beyond general therapy transfer. Thus, the inclusion of SARs should be seen as a way to disseminate evidence-based therapy, such as ABA (DICKSTEIN-FISCHER et al., 2018).

3 The Robot MARIA T21

The SAR MARIA T21 was developed at the Federal University of Espirito Santo (UFES/Brazil) by a multidisciplinary team in the field of robots for interaction with children with ASD and Trisomy 21 (T21). It is used in both learning and training in basic ADLs and in the evaluation of their dynamic characteristics while performing exercises and therapeutic activities (PANCERI et al., 2021; PANCERI et al., 2022). Figure 1 shows the robot MARIA T21.

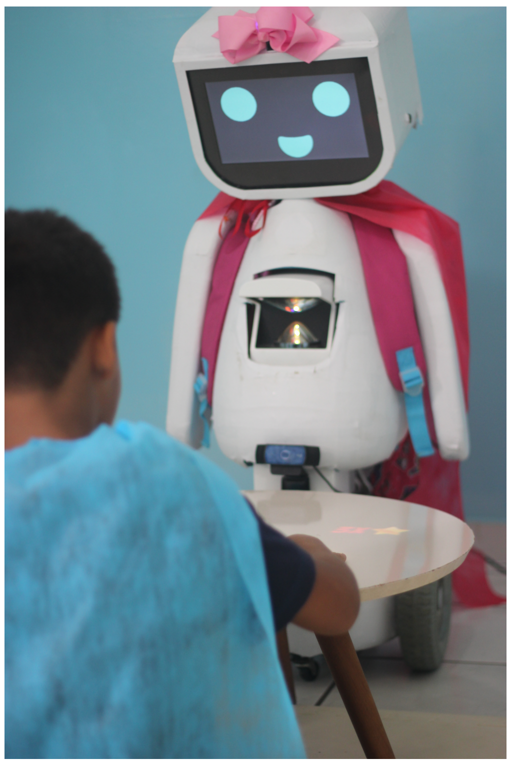


Figura 1 – MARIA T21

The recommended size of a SAR for children is approximately determined to be appropriate to the child's size to facilitate visual contact and be less intimidating in general (DICKSTEIN-FISCHER et al., 2018). In this way, the development of the robot considered approximating its dimensions to those of a child of approximately 8 years, which in addition to gains in portability, allows better adaptation to the child's needs to different therapeutic proposals (PANCERI et al., 2021).

The physical structure of the robot is covered with a touch-sensitive coating that adds the ability to feel and respond through touch, and has speakers that allow MARIA T21 to emit speeches, encouraging physical contact and allowing the tracking of therapeutic progress in terms of tactility. Along with other onboard devices such as the LIDAR (Light Detection and Ranging) sensor, it is also possible to track the child's progress in terms of proxemics during communication and recurring interaction with the robot. Figure 2 illustrates some of the onboard systems.

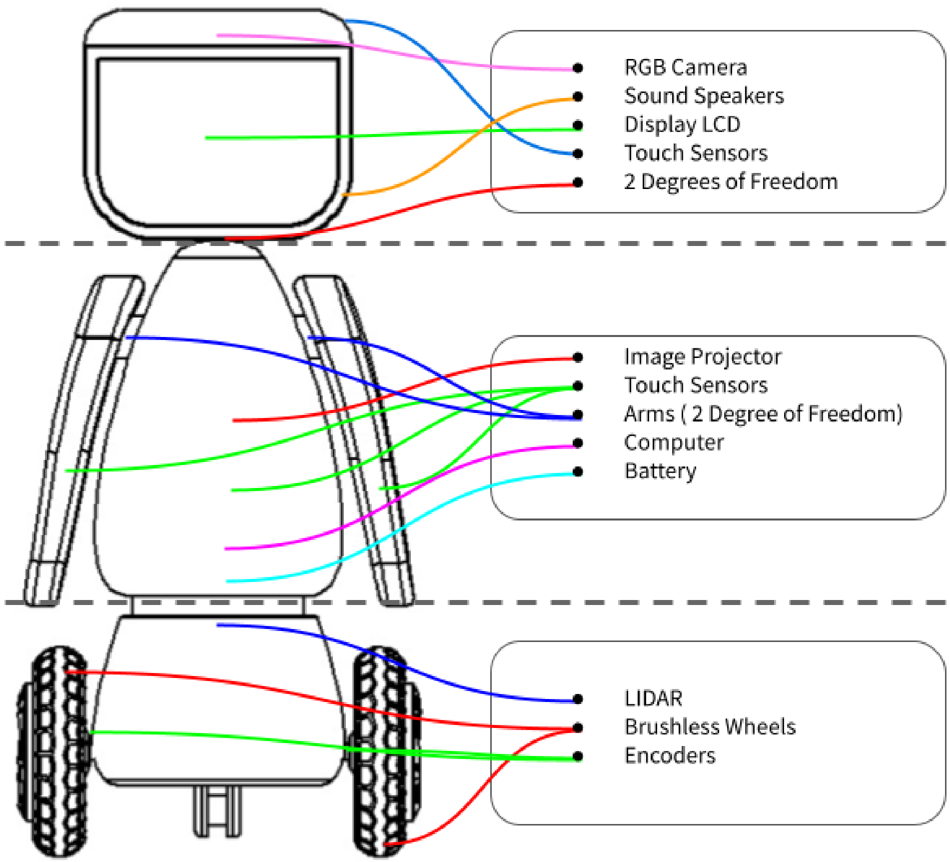


Figura 2 – MARIA T21 sensors

The LIDAR sensor used in the robot is capable of estimating the distance to obstacles (and also to the child) around it in two dimensions, using a rotating perpendicular scan of a laser light beam that reaches the obstacle (or child) and returns to the sensor. This way, the estimated distance between the sensor and the obstacle (or child) is proportional to the time between the emission and reception of the light beam. The emitted laser pulses have a wavelength that varies between 0.7 and 1000 µm, being contained in the infrared region of the electromagnetic spectrum. The LIDAR sensor used here is the RP LIDAR A1, developed by SLAMTEC, which was chosen because of its low cost when compared to other models available.

The 2D data obtained by this sensor can be used for mapping, localization and modeling of the environment around it. However, for the applications proposed by this work, a good part of these data can be discarded, as they refer to regions outside the zone of interest for the analysis of proxemics and for game control, where the serious game is being played by the child. Thus, data pre-processing is necessary in order to remove unwanted data, making the child's detection easier. Once the filtering process is carried out, the x and y child's posture (position and orientation) in the zone of interest is calculated through the average of the remaining points. This measurement considers that there is no obstacle or person in this zone besides the child. Algorithm 1 describes this process in a few words.

Algorithm 1 Processing and classification of LIDAR points cloud for child's posture identification

Require: $AllPts \in \Re^2$ of LIDAR points cloud
Ensure: (x, y) of child position at instant t
  $pt_v = [\ \ ]$ ▷ Empty Array pt_v for LIDAR valids points
  for $pt_i \in AllPts$ **do**
    if $pt_i \subset$ Game zone area **then**
      $pt_v = concat(pt_v, pt_i)$ ▷ Concat the point pt_i in pt_v
    end if
  end for
  Calculate mean and variance of pt_v array points.
  if $variance < threshold$ **then**
    $child_{xy}(t) = mean$
  else
    $child_{xy}(t) = child_{xy}(t-1)$ ▷ If the variation is greater, consider the current position as the previous position
  end if

The integrated projector LG HF85LA, 1500 Lumens, Full-HD, laser, embedded within the physical structure of the MARIA T21, along with the embedded cameras, allows for SGs to be projected on the floor with dimensions of approximately 2 x 3.5m, or on a table where the projection dimensions are smaller but it becomes possible to perform and evaluate activities with the hands and recognize emotions through the child's face.

As the SGs are projected, the robot may interact with the child, guiding him/her about errors and correct actions, and encouraging him/her through pre-recorded verbal testimonials (artificial voice) located in a bank of possible interaction and response possibilities, so that the responses to possible inquiries and interests of the child are more dynamic. To this end, the robot has an audio system composed of speakers and microphone. For this purpose, cloud robotics fundamentals are employed through the IBM Watson system[1]. This system provides a rich environment for the performance of various applications, facilitating asset management, systems management and engineering, and offers support for data science that helps deal with data analysis. Its applications are diverse, including education (RALSTON et al., 2019;

[1] <https://www.ibm.com/br-pt/watson>

OLIVEIRA et al., 2019), health (STRICKLAND, 2019), and the Internet of Things (IoT) (AHMED; KANNAN, 2021). Figure 3 illustrates the wireless communication between the robot MARIA T21 and the IBM Watson cloud system.

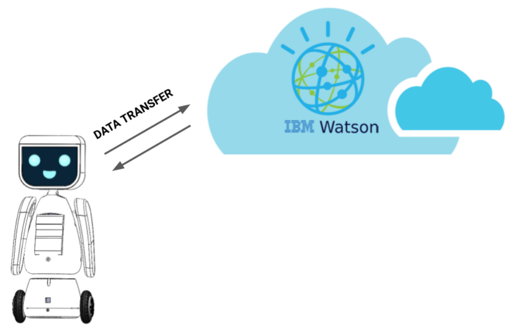


Figura 3 – MARIA T21 and IBM Cloud

The IBM Watson Speech-to-Text is capable of transcribing the content of an audio file containing phrases in different languages. The transcription process is performed through a request to the IBM server. In the same way, the Text-to-Speech service, the server response takes place in a few milliseconds, returning a JSON (JavaScript file) with some relevant information from the transcription, such as the confidence parameter that informs the level of confidence in the transcribed audio. Among the advantages of using cloud robotics are large storage spaces and greater processing power that allow the execution of computationally intensive tasks such as object recognition, computer vision, speech synthesis, and recognition (HU; TAY; WEN, 2012; WAN et al., 2016).

A 10.1-inch Touch Screen monitor represents the face of the robot MARIA T21, which can express five different emotions: great joy (I loved it), happiness, sadness, fear, and anger (Figure 4). The robot simulates eye movements and mouth blinks, accurately replicating the opening and closing of the eyes and lips. This synchronized motion effectively mimics natural facial expressions, including the act of speaking, where the lips move in coordination with the emission of the voice. The different emotions are interspersed so that the child-robot relationship is as close as possible to a routine and habitual interaction between two interlocutors. In addition, the set of emotions is another exploitable possibility of device operation by professionals, since recognizing different emotions, what caused them, and what to do to change them is one of the exploitable and teachable possibilities.

The computer vision system of the robot MARIA T21 is formed by two USB Logitech C920 PRO camera, which has a diagonal field of view of 78°, and a maximum resolution of 1080p@30fps. One camera is attached to the upper part of the robot's face to capture frontal images of the child's movement during therapy and the other positioned at the base of the robot to capture participants more broadly. For the applications proposed in this work, the

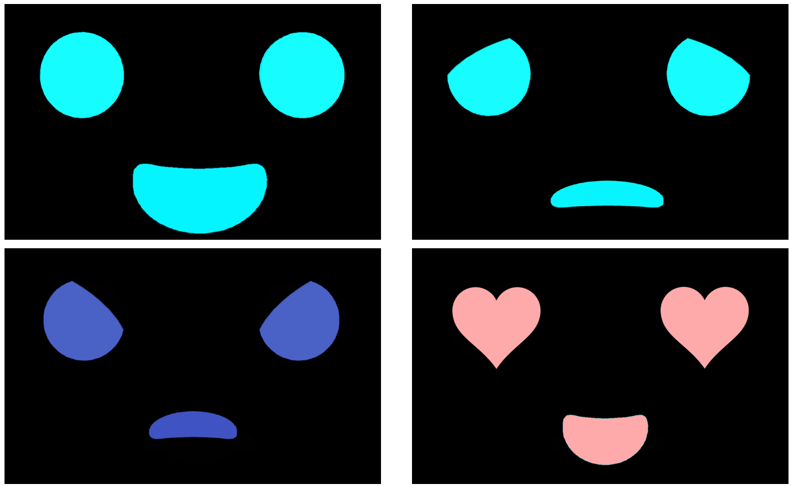


Figura 4 – MARIA T21 face emotions

main function of the computer vision system is to identify the child's body movement. For this, an open source cross-platform framework, called MediaPipe[2] and developed by Google, offers and enables the creation of machine learning solutions for computer vision such as real-time image analysis. Most of the libraries already developed use the Python programming language, being a versatile tool that allows adapting to the environment conditions. Additionally, its integration with Unity allows the child to interact and control the SG only from the sensing through gestures, actions or expressions, while allowing data to be collected in order to analyze how the child reacts (LUGARESI et al., 2019).Thus, all this integrated system is capable of capturing information from images of human bodies and providing spatial information about joints. In this way, it is possible to calculate a series of useful parameters for physical SGs, such as: estimated child's posture in the environment, limb angles, center of mass and gestures.

In this work, the Robot Operating System (ROS) is used to provide the necessary middleware for the development of the local network that performs the communication between the therapist's computer or tablet and the robot. ROS is open source and allows the development of robotic systems, in a way that it is possible to manage device drivers and other components used to abstract the hardware. It contains visualization and simulation tools, client-server architecture management, communication protocol, simplifying the exchange of messages between different processes (QUIGLEY M.; CONLEY, 2009).

Furthermore, it was sought to ensure that the robot could directly help not only children with ASD and T21, but also families and therapists. To this end, the robot now has optional accessories that add to the child's and health professionals' experience, enabling new ways to interact with projections on the floor or table, and providing more data than

[2] <https://developers.google.com/mediapipe/solutions>

just observational data from professionals and family members. These are: touch-sensitive carpet, mirrored table for projection and hand-controlled game, and four cameras structure positioned at strategic and adjustable points of the environment.

A sensing mat was developed to be used when the child is interacting with the robot, which uses a material known as Velostat. This material has the ability to change its electrical conductance when placed under pressure (PANCERI et al., 2021). Figure 5 shows the basic concept of an electrical circuit, known as voltage divider, capable of transforming the variation of pressure applied on the material in proportional electrical voltage. This electrical information is read and processed by a microcontroller in order to provide real pressure information.

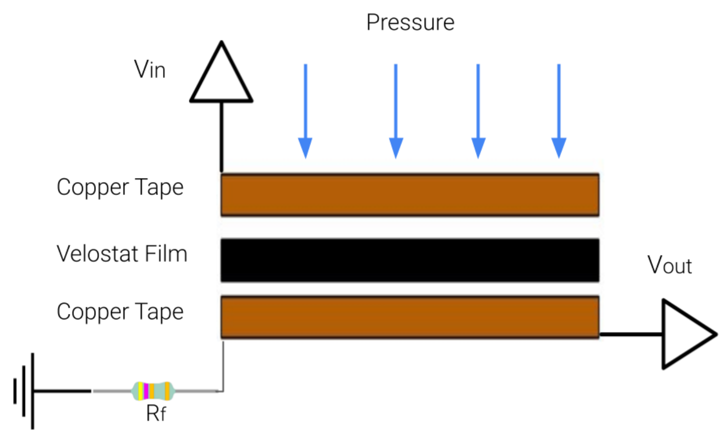


Figura 5 – Basic operating principle of sensitive mat

In Figure 5 it is possible to observe two copper conductors separated by the Velostat. This configuration is equivalent to two wires separated by a resistor, which is a variable resistor. In sequence there is also a resistor with a fixed value in series. Subjecting this circuit to an electrical potential difference of 3.3 V, a voltage proportional to the pressure is found between the Velostat and the fixed resistor. Considering a measurement range between 15 and 60kg, similar to a child's typical weight, the output voltage ratio can be expressed by means of the Equation 3.1. In this equation, V_{out} is the output voltage, V_{in} the input voltage (3.3 V), R_f the value of the fixed resistor expressed in Ohms, ρ the exerted pressure on the material, and K a constant that converts pressure information into resistance. From test weights for calibration, it is possible to find the relationship $\frac{K}{\rho}$ empirically, calibrating the system.

$$V_{out} = V_{in} \cdot \frac{R_f}{R_f + \frac{K}{\rho}} \tag{3.1}$$

According to Figure 6, the mat is assembled using a sheet of normal paper with copper strips arranged vertically, and another sheet with strips arranged horizontally, separated by a Velostat film. Figure 6 presents a very important concept for the mat's operation. In red, it can be seen that when one strip is selected vertically and another horizontally, it is possible to get an intersection, which corresponds to a pressure point that can be read independently.

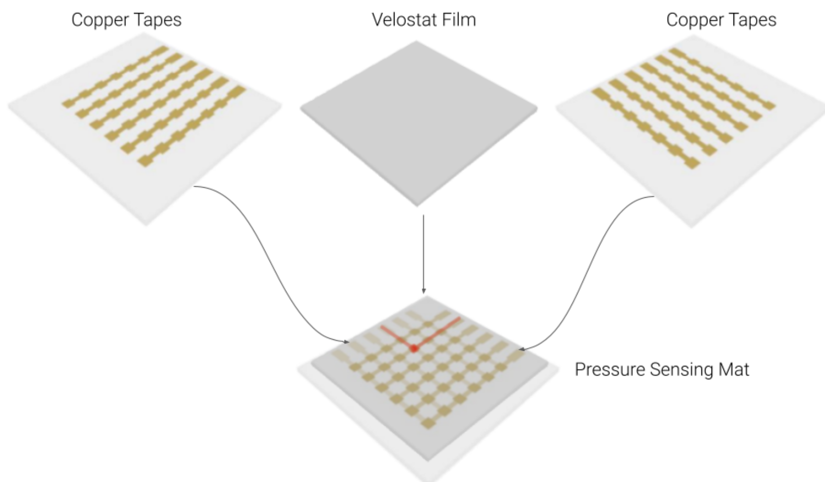


Figura 6 – Mat assembly diagram

The circuit for scanning all possibilities of intersections was based on 2 CD74HC4067 16-channel multiplexers, thus, 16 copper tapes were used on each paper sheet, totaling 256 reading points. Figure 7 shows a wiring diagram of the components involved in processing the mat data. It can be seen that the mat's conversion of voltage signals from analog to digital is performed by Espressif's ESP32 microcontroller, via an I2C bus. The digitized information is then sent via Bluetooth to a computer that transforms the information from each point on the mat into pressure information, also carrying out filtering and interpolation processes. This information can be seen visually through a heat map. Through Algorithm 1 it is possible to generally understand how the microcontroller scans the 256 pressure points on the mat.

Algorithm 2 Mat Reading Routine

```
while true do
    for (n = 1; n <= 16; n++) do                     ▷ Copper route sweep
        Multiplexer_1(x(n), HIGH)                     ▷ Set x(n) copper tape to high 3.3V
        for (m = 1; m <= 16; m++) do
            Multiplexer_2(y(m))                       ▷ Connect y(m) copper tape to ESP32 A/D pin
            Value = AD_Converter()                    ▷ Read y(m) copper tape voltage value
            Bluetooth(n, m, Value)                    ▷ Send x(n), y(m) position and voltage value to server
        end for
        Multiplexer_1(x(n), LOW)                      ▷ Set x(n) copper tape to low 0.0V
    end for
end while
```

The values of x are defined as a reference. For each voltage value assumed by x(1) the corresponding 16 points of y are read, and then the same is done for x(2) up to x(16).

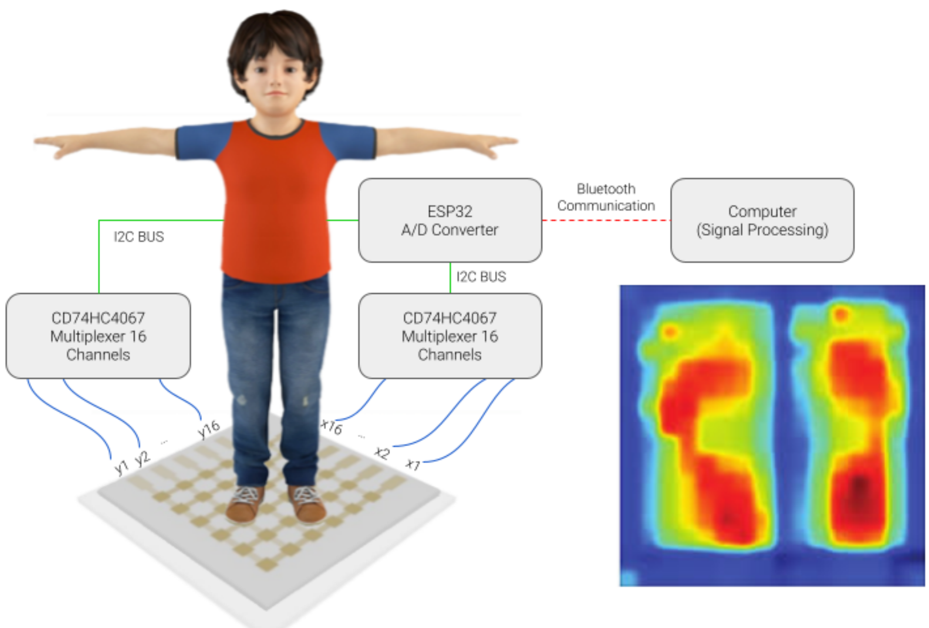


Figura 7 – Mat system component's diagram

4 Serious Games (SGs)

The use of SGs has grown in various industries, including health, safety, defense, education, and business. For example, business simulation games allow players to experience making strategic decisions and managing resources in simulated environments, preparing them for similar challenges in the real world (ALMEIDA L.; SILVA, 2019). Educational games, on the other hand, help students learn complex concepts in a fun and engaging way (QIAN; CLARK, 2016).

Furthermore, SGs have also been used for therapeutic purposes, such as the treatment of psychological and mental health disorders. These therapeutic games offer patients a safe and controlled way to explore their concerns and learn useful skills to cope with their conditions (PANCERI J.A.C.; FREITAS, 2020; KANKAANRANTA M.H.; NEITTAANMäKI, 2008).

In the therapy of children with ASD, SGs have been successfully used as a teaching tool and for the development of social and communication skills, as well as the reduction of problematic behaviors (NOOR; SHAHBODIN; PEE, 2012; SILVA et al., 2021).

The interactivity of these games occurs mainly in four ways: conventional computers, mobile phones/tablets, Virtual Reality (VR) glasses, and smart environments (using range sensors). However, in some situations, some of these technologies cannot be applied. For example, VR glasses, which could make the game even more immersive at first, may cause a lot of discomfort in children with ASD, making their use unfeasible. Therefore, some studies, such as (VALENCIA et al., 2017), opted for the adoption of projectors and RGB-D cameras, creating a semi-immersive interactive environment, where children can play using their own body. For this, the child's movements are captured by RGB-D cameras (Kinects) scattered throughout a playroom, allowing interaction with the game, which is projected on a wall or even on the floor (VALENCIA et al., 2017).

According to the study by Dicheva et al. (2015), SGs are effective in improving social skills in children with ASD, including the ability to understand the emotions of others and the ability to communicate effectively. Additionally, the study found that these children who participated in this type of therapy showed a significant improvement in their attention and concentration skills (DICHEVA et al., 2015).

In general, research suggests that SGs can be a valuable tool in the therapy of children with ASD. Although further research is needed to fully evaluate the effectiveness of these therapeutic games, they are promising as a complementary tool in the therapy of children with ASD (QIAN; CLARK, 2016; CASSIDY S.; STENGER, 2015; SILVA et al., 2021).

With the constant evolution of technology, it is expected that SGs use will continue to grow and expand in various areas. This work describes the proposal for the foundation, design, architecture, and development of DDA SGs that make use of the benefits of SAR and Child-Robot Interaction (CRI) concepts in the therapy of children with ASD according to the ABA therapy.

4.1 Dynamic Difficulty Adjustment (DDA)

DDA is a game design technique that dynamically adjusts the game difficulty in real-time based on the player's skills and performance. DDA is implemented using machine learning algorithms to adaptively adjust the game difficulty and maintain an optimal level of challenge for the player, while avoiding excessive frustration, which is crucial for ensuring engagement and learning progress (PFAU; SMEDDINCK; MALAKA, 2020; PENG et al., 2019; KRISTAN et al., 2020).

DDA is achieved by continuously monitoring the player's performance and dynamically modifying the game difficulty based on that performance. For instance, if the player is achieving success easily, the difficulty is increased, while if the player is struggling, the difficulty is decreased. This allows the player to progress continuously in their learning and maintain an appropriate level of challenge. However, careful balancing of the difficulty is necessary to avoid extreme fluctuations that may negatively impact the player's experience.

Modulation can be implemented through various means, such as increasing/decreasing game speed, introducing/removing obstacles, or reducing/augmenting target size (VANG, 2022). Modulating the difficulty in serious games is important as it enables the game to challenge the players without overwhelming them, thereby fostering motivation and engagement throughout the therapeutic process.

Personalization of therapeutic games and difficulty modulation can also aid therapists in monitoring the player's progress over time. By adjusting the game difficulty and customizing it to the player's needs, therapists can assess the player's performance and adapt their therapy accordingly (HOCINE; GOUAÏCH; LORETO, 2011; SHOHIEB; DOENYAS; ELHADY, 2022).

In the field of ABA, it is common practice to begin with high-probability requests, which are tasks that individuals can easily perform, before transitioning to more challenging requests, such as learning a new skill. When using a robot to teach a child a new skill, it is crucial for the robot to have a set of requests that the child already masters (PENG et al., 2019). These requests can be utilized during the initial interactions with the child to build their experience in interacting with the robot, and this can be achieved through SGs.

The core concept involves the development of in-game actuators that dynamically adapt themselves based on player input, aiming to enhance the player's gaming experience. This adaptation encompasses aspects such as increased engagement, progressively escalating challenges, and mitigating repetitive frustrations (PENG et al., 2019; PFAU; SMEDDINCK; MALAKA, 2020; KRISTAN et al., 2020).

4.2 Software Requirements

In this section, the primary software applications utilized to address the specific requirements of the study is discussed, including the development of touchless gameplay techniques and the facilitation of communication between SGs and SAR.

4.2.1 MediaPipe

MediaPipe is a versatile software development framework known for its flexibility and efficiency in real-time media processing. It is widely used in both academic research and commercial applications due to its comprehensive infrastructure that allows the construction of modular pipelines. These pipelines seamlessly connect different processing modules, facilitating the processing of media data. MediaPipe supports multiple platforms, including Android, iOS, Linux, and Raspberry Pi, making it highly adaptable. With its native integration with TensorFlow, a popular machine learning library, MediaPipe simplifies the incorporation of machine learning algorithms into media processing pipelines. Python, a versatile programming language, is commonly used with MediaPipe, allowing developers to adapt it to different environments. The integration of MediaPipe with Unity enables children to interact with and control the SGs using gestures, actions, or expressions, while also facilitating data collection for analyzing children's responses to the SGs (LUGARESI et al., 2019).

4.2.2 Open Source Computer Vision Library

OpenCV (Open Source Computer Vision Library), developed initially by Intel in 1999, is a widely used open-source library for image processing and computer vision tasks. Written primarily in C++, OpenCV also provides support for multiple programming languages, including Python and Java. Its main objective is to offer a comprehensive set of algorithms and functions to perform various computer vision-related tasks (BRADSKI; KAEHLER, 2008).

OpenCV consists of several key modules. The Imgproc module enables pre-processing and image processing operations such as filtering, geometric transformations, segmentation, and morphological operations. The Objdetect module provides features for object detection and recognition, including face detection, general object detection, and training of feature-based classifiers. The Machine Learning module incorporates algorithms for classification and regression tasks, including methods based on decision trees, neural networks, and Support Vector Machines (FARABET et al., 2013).

In addition to these core modules, OpenCV supports advanced features such as pattern recognition. Due to its open-source nature and widespread popularity, OpenCV has found extensive adoption in computer vision applications across various fields, including robotics, industrial automation, computer vision research, virtual reality, security, medicine, and many others. Its versatility and rich functionality make it a valuable tool for developers and researchers in the field of computer vision (BRADSKI; KAEHLER, 2008).

4.2.3 Unity

Unity 3D is a game development tool used in the gaming industry and interactive applications, such as the SGs in this study. It is a multi-platform game engine that allows the creation of immersive 2D and 3D experiences for a variety of devices, including computers, consoles, mobile devices, and virtual reality (HAAS, 2014). Among its appealing features is its user-friendly interface and accessibility, making it a popular choice for both experienced developers and beginners, along with its intuitive interface and extensive documentation that facilitates learning and creation. Additionally, the Unity 3D supports multiple programming languages, including C# and JavaScript, allowing developers to choose the language they are most comfortable with (JÁCOME et al., 2021).

One of the standout features of Unity 3D is its ability to create high-quality graphics, supporting advanced visual effects, dynamic shadows, global illumination, and realistic materials. This enables the creation of immersive and visually appealing environments, enhancing the experience for children with ASD. Furthermore, Unity 3D offers resources for educational game development, including animation, collision detection, and audio. These features enable the creation of interactive interactions, visual and auditory feedback, engaging challenges, and immersive learning experiences within the game.

4.3 Hardware Requirements

In addition to the SAR and all its embedded and external technology presented in Chapter 3, including the sensing mat and camera systems, for the proper operation and control of the SAR and SGs, a Dell Gamer Notebook G3-3500-A40 was required. This notebook was used for communication purposes, facilitated by a dual-band Archer C6 wireless router.

4.4 Cognitive SGs

The cognitive benefits depend on the context and are enhanced by social interaction. Therefore, the effectiveness of the SAR intervention should be analyzed in real learning environments involving user learning in different spatial and social contexts, as environmental conditions affect the quality of SAR interactions and the resulting useful outcomes (CLABAUGH et al., 2019).

In this study, SGs were developed, evaluated, and validated, with an emphasis on the development of cognitive skills in different contexts. It is worth noting that despite these games were focused on cognitive skills, there is always an interconnection and reinforcement of motor and functional functions during their execution.

4.4.1 Memo

The Memô SG draws inspiration from the electronic game Simon, a popular memory and dexterity challenge created by Ralph H. Baer and Howard J. Morrison, which debuted commercially in 1978. Simon consists of an electronic unit with four colored buttons, each corresponding to a specific sound or light (PROCTOR, 2011).

The game Memô comprises three colored squares – yellow, blue, and red – projected onto a surface using the MARIA T21 technology. These squares emit sounds upon flashing. Figure 8 shows in the left the home screen and in the right the phase 2 screen. The child must replicate the presented sequence of squares been highlighted, where one of the squares is randomly highlighted for two seconds and emits a musical note. With time the difficult increases, so more colors and notes are added to the sequence. For instance, the first level highlights only one color, the second level highlights two colors (which may be identical or distinct), and so forth. A cue signals the end of the sequence, indicating that it is the player's turn to replicate the sequence exactly as presented.

Memô utilizes the MARIA T21's top camera and the MediaPipe technology to recognize players' hand gestures, enabling efficient control (see Figure 9).

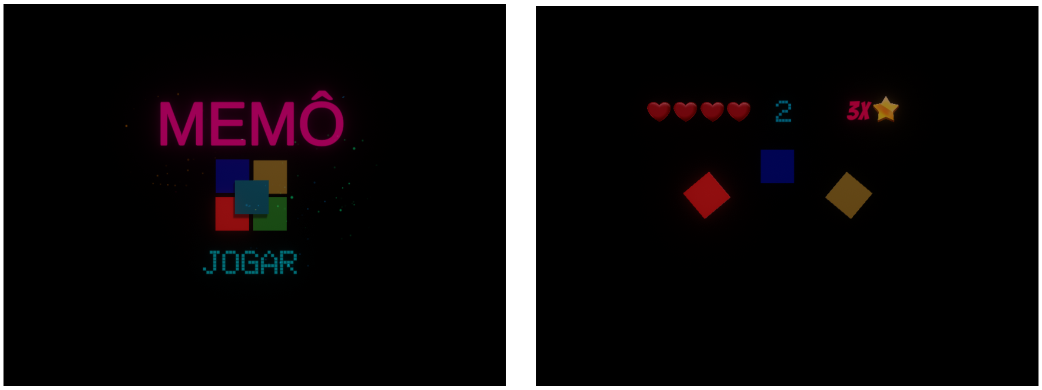


Figura 8 – SG Memô Interface

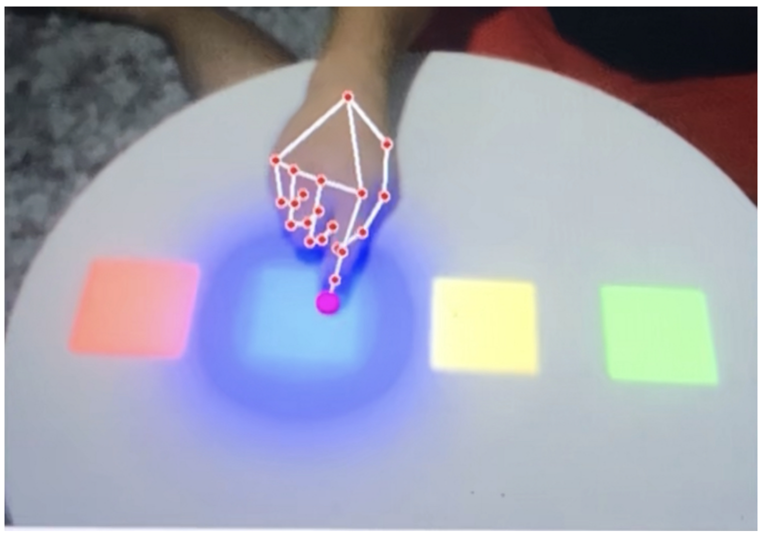


Figura 9 – Memô using MediaPipe Pose Landmark Detection

4.4.2 Game's Objective

The primary objective of the SG Memô is to enhance children's memory and attention skills. Players are required to repeat sequences of colors and sounds presented by the game as the difficulty level escalates.

4.4.3 Dynamic Difficulty Adjustment in this SG

Figure 10 illustrates how the DDA modulates the game across three difficulty levels. The Memô SG employs DDA to maintain engagement by adapting to performance, attention level, and score.

Regarding gameplay performance:

- After the third level, if two consecutive errors occur, the game will reiterate the last color three times before introducing a new color.

- From the fifth level onward, if the child takes longer than 8 s to choose a color in the sequence, the game will visually highlight the color once per sequence.

In terms of attention:

- If the child's face deviates from the direction of the game table, MARIA T21 will emit random messages to recapture their attention.

- If distraction occurs during the reproduction of the color sequence to be memorized, in addition to the call message, the sequence will pause and restart.

Scoring:

- The score is diminished whenever assistance modulations and consecutive repetitions of colors are activated.

Upon completion, a text file records the total playtime, number of assists, displayed attention messages, and the achieved score.

The development of this SG led to the publication of an article in the proceedings of the IX Latin American Congress of Biomedical Engineering 2022 and the XXVIII Brazilian Congress of Biomedical Engineering 2022 (FREITAS et al., 2022).

4.4.4 Goblin Gold

The purpose of SG Goblin Gold is to safeguard a central artifact from continuous enemy attacks. These adversaries emerge at random points on the map, gradually converging towards the objective. To enhance comprehension, appropriate visual representations have been adopted, where the central artifact takes the form of a "treasure chest", and the adversaries are represented as small monsters.

The deliberate choice of the "Tower Defense" game genre stems from its demand for defending an objective against a series of adversaries, necessitating constant player focus to maximize survival. This choice fosters concentration and attention, with scores driven by positive reinforcements as players progress.

Gameplay involves the player focusing on an approaching enemy for a specific time interval to protect the artifact and accumulate points. Focusing reduces the enemy's speed, while visual particles are emitted to sustain engagement through positive reinforcement. Maintaining sufficient focus leads to the enemy's disappearance, granting points and visual stimuli. Figure 11 displays the game interface.

As the game progresses, new enemies emerge, requiring players to devise strategies for eliminating them before their numbers accumulate. The challenge extends beyond focal

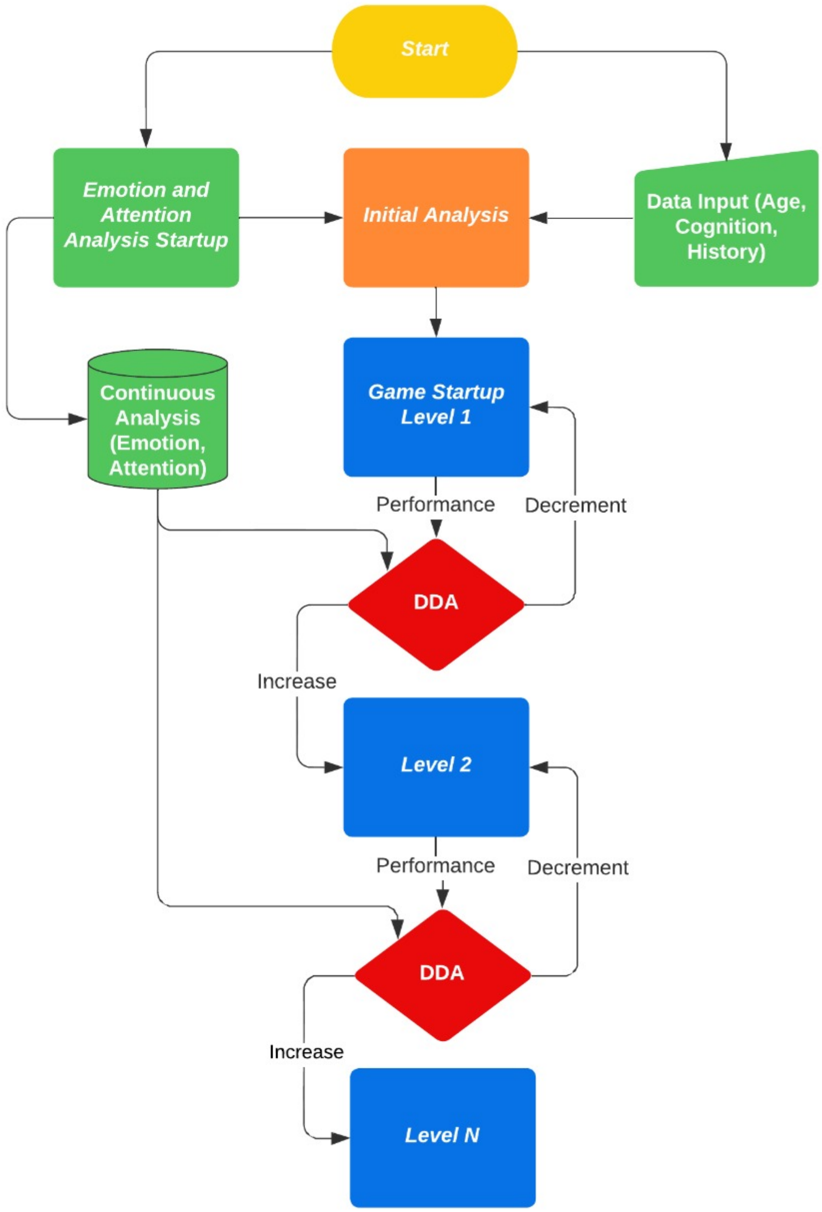


Figura 10 – Details of the DDA applied for the SG Memô

attention, encouraging the utilization of peripheral vision to manage enemies beyond direct focus.

Player progress is marked by ascending levels, increasing speed, enemy count, and introducing changes in the environment. These elements differentiate levels, offering progressively complex challenges. If an enemy reaches the objective, life points are reduced, culminating in a reward proportional to the score at the game's conclusion.

The enemies are classified into four distinct types, each with a unique combination of

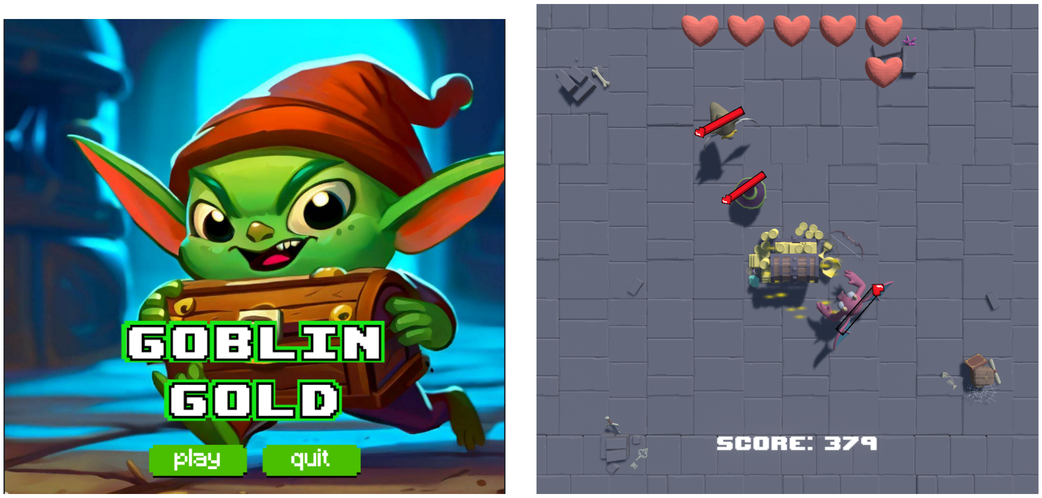


Figura 11 – Interface SG Goblin Gold

attributes to add variety to the gameplay. This approach aims to maintain challenging and dynamic progression, alternating between enemy types and necessitating the use of specific abilities to defeat them.

- Type A - High-speed, low maximum life enemies. They experience significant speed reduction when focused by the player, compensating for their high speed and rewarding quick reflexes. They yield the second-lowest base score ($baseScore = 3$) upon defeat and inflict one unit of damage to the player's lives ($damage = 1$).
- Type B - Balanced enemies across attributes. They possess intermediate speed and maximum life, experiencing considerable speed reduction when player-focused. They yield the second-highest base score ($baseScore = 4$) and inflict two units of damage ($damage = 2$).
- Type C - Challenging enemies rewarding prolonged focus. They possess the highest maximum life among enemy types and the slowest speed. They do not experience speed reduction when exposed to player focus. They yield the highest score upon defeat ($baseScore = 5$) and deal the most damage when reaching the chest ($damage = 4$).
- Type D - Low-challenge enemies designed to introduce players to the learning curve. They are slow and have low maximum life. They experience minor speed reduction due to their already reduced speed. They yield the lowest base score ($baseScore = 2$) and deal two points of damage ($damage = 2$) upon reaching the chest.

Three-dimensional models of selected enemies have been designed to exhibit variations within each type, maintaining visual stimulation and the organic feel of the game while avoiding the occurrence of identical models simultaneously. This choice also considers distinctive visual identities for each enemy classification, enabling type identification solely based on appearance. For instance, Type A enemies' appearance reflects their speed and fragility, featuring small, airborne creatures with rapid wing movements. In contrast, Type C enemies are notably large with slower animations. Figure 12 showcases the four types of Goblin Gold enemies.

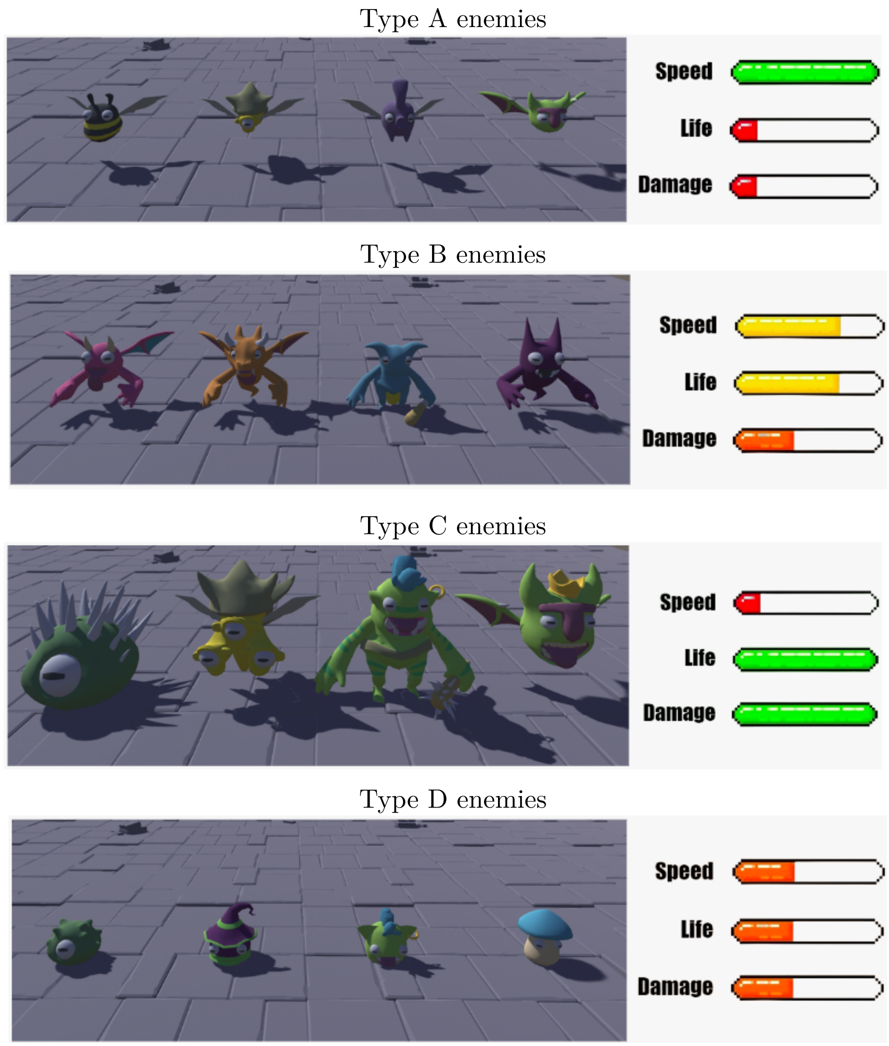


Figura 12 – SG Goblin Gold enemies types

4.4.5 Game Objective

The primary focus of SG Goblin Gold is to foster attention, concentration, reduction of ocular stereotypies, and enhancement of social skills such as eye contact through interaction via eye-tracking technology.

4.4.5.1 Dynamic Difficulty Adjustment in this SG

The monitoring of performance and DDA is accomplished using global variables and their associated contexts. Some of these variables are described in Table 2.

Table 2 – Global Variables

modulHealthMult	Global base multiplier for enemy health
modulSpeedMult	Global base multiplier for enemy speed
levelMultiplier	Level multiplier
distanceEye	Minimum required distance from focus position to enemy
winStreak	Number of consecutive wins
loseStreak	Number of consecutive losses
repeatLevel	Number of global repetitions
totalScore	Total score obtained throughout a game session, encompassing the entire gameplay scope
levelScore	Total score obtained in a specific level
finalPerformance	Player performance per level, calculated based on the ratio of remaining lives to total lives
levelTime	Time taken to complete a level
totalSpawn	Total number of enemies faced in the current level
simultaneousAllowed	Maximum number of simultaneous enemies that can appear in the level

This SG has been designed to provide children with the opportunity to make mistakes and adapt to the learning curve, allowing them to fail in levels a few times before completing the game. A victory in a level is achieved by reaching the minimum performance set for that level, but some stages can be repeated if the child does not achieve the desired minimum outcome or when the player runs out of lives, resulting in a defeat. When a victory is achieved, the global win counter is incremented. If a level is repeated, the win counter is not increased, but the repetition counter is. The player loses the game upon encountering their third consecutive loss.

At the start of each level, the player begins with the maximum number of lives, regardless of how many lives they had in the previous level. Upon completing a level, a performance calculation is carried out, reflecting the child's performance in that level. This calculation is based on the ratio of remaining lives to the total number of lives. Achieving a performance of 70% or higher twice in a row results in a 20% increase to the base enemy health multiplier (*modulHealthMult*). Upon achieving this stage for the third consecutive time, a 20% increase is also applied to the base enemy speed multiplier (*modulSpeedMult*). Similarly, when a child encounters the game over screen due to failing a level (losing all their lives), the base enemy health multiplier is decreased by 10%, and if this happens for the second time consecutively, the enemy speed is also reduced by 10% of its base value. While there is no maximum limit to how much these variables can be increased, the minimum values for health and speed are limited to 40% and 60% respectively of their base values, to restrain the extent to which the game can be made easier through such adjustments. The level multipliers (*levelMultiplier*) have been designed to facilitate accurate and balanced score calculation, reflecting the child's overall performance when completing the game, taking into account possible level repetitions. Equation 4.1 presents the way to calculate score according to the parameters of the game.

$$\text{score} = \text{baseScore} \cdot \text{scoreMultiplier} \tag{4.1}$$

where *score* represents the score obtained upon defeating an enemy, and *baseScore* is the attribute of the defeated enemy corresponding to the base score value. The *scoreMultiplier* is the multiplier applied to this base value, resulting from the sum of other multipliers, represented in the equation:

$$\begin{aligned} \text{scoreMultiplier} = 1 + \mathit{levelMultiplier} + \left(\frac{\mathit{winStreak}}{2}\right) \cdot 2 \\ + (\mathit{modulHealthMult} - 1) \cdot 2 + (\mathit{modulSpeedMult} - 1) \cdot 2 \end{aligned} \tag{4.2}$$

where *levelMultiplier* is the level multiplier, *winStreak* is the win counter, and *modulHealthMult* and *modulSpeedMult* are the multipliers affecting enemy health and speed, respectively.

When a child performs well in each stage and progresses without repetitions, they reach higher levels with larger multipliers, unlike those who need to repeat some stages before advancing. Levels that do not require adjustments due to repetitions have a null level multiplier.

This way, players who progress quickly and perform well with fewer repetitions will be rewarded with higher multipliers, reflecting their overall better performance throughout the game and providing a more accurate assessment of the final scores.

The modularization of levels has been designed to address and analyze specific skills of the children. Each stage has a total number of enemies to defeat and a varied proportion of enemy types.

1. Level 1: Explanation and Familiarization Round
   - $\mathit{totalSpawn} = 6$;
   - $\mathit{simultaneousAllowed} = 2$;
   - $\mathit{levelMultiplier} = 0$;
   - Enemy type proportion: Type D only;
   - Enemy spawning is unilateral, restricted to a single axis;
   - At the end of the level, the performance calculation based on remaining lives is carried out, and progression occurs to the next level:

    - Level 2 - Type X if *finalPerformance* is below 40%, and *repeatLevel* is incremented by one;
    - Level 2 - Type Y if *finalPerformance* is 40% or higher;

2. Level 2 - Type X:
    - *totalSpawn* = 6;
    - *simultaneousAllowed* = 1;
    - *levelMultiplier* = 0;
    - Enemy type proportion: Type D only;
    - Enemies can spawn from all directions;
    - Progression to Level 2 - Type Y regardless of performance;
3. Level 2 - Type Y:
    - *totalSpawn* = 8;
    - *simultaneousAllowed* = 2;
    - *levelMultiplier* = (2 - *repeatLevel*);
    - Enemy type proportion: Types A and D, according to the proportion (1A, 0, 0, 1D);
    - Enemies can spawn from all directions;
    - At the end of the level:
        - If *finalPerformance* is below 60%: player remains in the same level, and *repeatLevel* is incremented. From the second global repetition onwards, *modulSpeedMult* is reduced by 10%, and *modulHealthMult* is reduced by 20%;
        - If *finalPerformance* is 60% or higher, or *repeatLevel* is three: player advances to the next level.
4. Level 3: Evaluation of Reaction Speed
    - *totalSpawn* = 10;
    - *simultaneousAllowed* = 2;
    - *levelMultiplier* = 0;
    - Enemy type proportion: Type A only;
    - At the end of the level, performance is recorded, and the stage is repeated once before moving to the next level, regardless of the obtained performance. There will be no repetition counter incrementation based on performance during this stage;
5. Level 4: Evaluation of Focus Ability
    - *totalSpawn* = 3;
    - *simultaneousAllowed* = 1;
    - *levelMultiplier* = 0;
    - Enemy type proportion: Type C only;
    - At the end of the level, performance is recorded, and the stage is repeated once

before moving to the next level, regardless of the obtained performance. There will be no repetition counter incrementation based on performance during this stage;

6. Level 5: Evaluation of Peripheral Vision
   - *totalSpawn* = 7;
   - *simultaneousAllowed* = 2;
   - *levelMultiplier* = 0;
   - Enemy type proportion: Type B only;
   - At the end of the level, performance is recorded, and the stage is repeated once before moving to the next level, regardless of the obtained performance. There will be no repetition counter incrementation based on performance during this stage;
7. Level 6: Dynamic Skill Evaluation
   - *totalSpawn* = 12;
   - *simultaneousAllowed* = 2;
   - *levelMultiplier* = 0;
   - Enemy type proportion: Types A, B, and D, respecting the proportion (2A, 4B, 0, 1D);
   - At the end of the level:
     - If *finalPerformance* is 40% or lower: the stage is repeated, and *repeatLevel* is incremented. In the next attempt, Type D enemies are removed, and *totalSpawn* is set to 9;
     - If *finalPerformance* is below 60%: the stage is repeated, *repeatLevel* is incremented, and *totalSpawn* is set to 9. If in the previous attempt, Type D enemies were removed, in the next attempt, they are reintroduced, and *simultaneousAllowed* is set to 1;
     - If *finalPerformance* is 60% or higher but less than 79%: advance to the next stage;
     - If *finalPerformance* is 80% or higher in the first attempt: advance to the next stage, replacing Level 7 values with the following: *simultaneousAllowed* = 3 and *levelMultiplier* = (8 - *repeatLevel*).
8. Level 7: Advanced Dynamic Skill Evaluation
   - *totalSpawn* = 12;
   - *simultaneousAllowed* = 2;
   - *levelMultiplier* = (4 - *repeatLevel*);
   - Enemy type proportion: All enemy types, respecting the proportion (2A, 4B, 1C, 1D);
   - At the end of the level:
     - If *finalPerformance* is below 60%: the stage is repeated, *repeatLevel* is incre-

mented, and *levelMultiplier* is set to 0. If in the previous attempt, *simultaneousAllowed* was 3, it returns to 2;

- If *finalPerformance* is 60% or higher but less than 79%: the game ends, and the final score is equal to *totalScore* obtained so far;
- If *finalPerformance* is 80% or higher: the game ends, *levelScore* is multiplied by 3 and added to *totalScore*, becoming the final game score;

Finally, it is important to note that the game can be terminated prematurely under two conditions: when *repeatLevel* reaches 5 or when *loseStreak* reaches 3. The generated text file records the Cartesian coordinates of where enemies were eliminated in each stage, game time, total points, and modulations of enemy speed and health values throughout the execution.

The development of this SG resulted in an article published in the annals of the IX Latin American Congress of Biomedical Engineering 2022 and the XXVIII Brazilian Congress of Biomedical Engineering 2022 (NEGRI et al., 2022).

4.4.6 MARIA's Homework

The SG MARIA's Homework utilizes a table as the application surface and the robot MARIA T21 for projection, reading questions, indicating correct and incorrect answers, and actively engaging the child. The game is structured as a quiz comprising questions from six different thematic areas, encompassing a variety of topics relevant to academic and social development. Each thematic area consists of 16 questions, with 6 at an easy level, 5 at a moderate level, and 5 at a challenging level. This design allows the child to be appropriately challenged based on his/her abilities and prior knowledge. Figure 13 illustrates the assessment areas, collectively forming a bank of 96 questions.

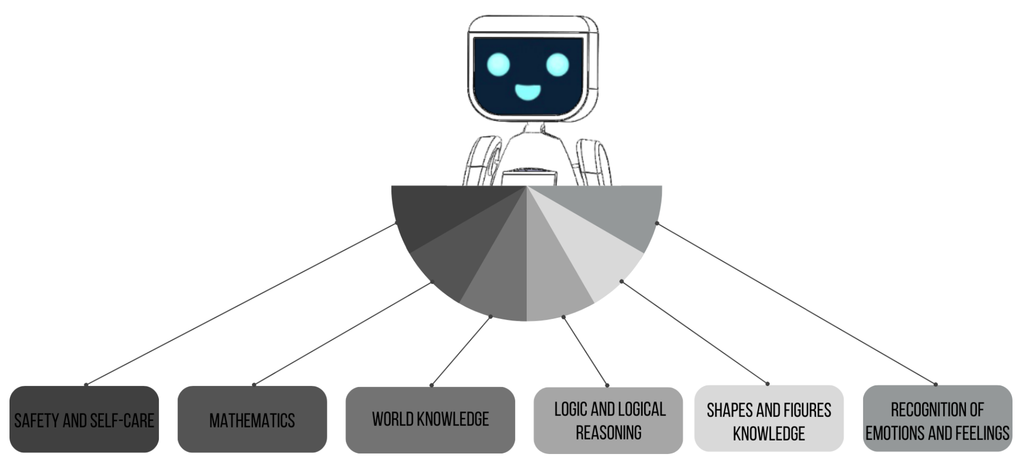


Figura 13 – Assessment Areas of MARIA's Homework

Each assessment area in the Maria's Homework game is fundamental to the overall development of children with ASD. Each of these areas addresses specific skills that are essential for their cognitive, social, and emotional growth, as listed below:

1. Safety and self-care: Teaching safety and self-care is crucial to ensure that children with ASD are aware of potential dangers in their environment and can take appropriate measures to protect themselves. This includes teaching safety rules at home, school, and public places, such as safely crossing the street, identifying household hazards, and adopting personal hygiene habits.
2. Mathematics: Mathematics education is important for developing numerical skills, logical reasoning, problem-solving, and organizational skills. Through the game, children can learn basic mathematical concepts such as counting, number identification, pattern recognition, and simple operations.
3. World knowledge: Teaching about the world around them is essential to expand the knowledge repertoire of children. This includes teaching geography, history, natural sciences, different cultures, and current events. Through the game, children can learn relevant facts and concepts, enhancing their understanding and interest in the world they live in.
4. Logic and logical reasoning: Developing logical and reasoning skills is crucial for critical thinking, problem-solving, and decision-making. The game provides opportunities for these children to exercise their logical thinking by identifying patterns, making inferences, and applying strategies to solve challenges.
5. Shape and figure recognition: Teaching geometric shapes and figures helps children develop visual perception skills, fine motor coordination, and spatial understanding. The game offers an interactive platform to explore and identify shapes and figures, fostering the development of these skills.
6. Recognition of emotions and feelings: Teaching these children about emotions and feelings is essential for the development of social and emotional skills. Through the game, children can learn to recognize and identify different emotions, express their own emotions, and understand the emotions of others – all of which are fundamental for communication and social interaction.

Each application corresponds to 36 questions, with the first question in each thematic area always being easy to guide the subsequent difficulty levels of each subject. As a result, each child will have answered 6 questions from each thematic area at the end. At the discretion of the facilitators and considering the child's reading difficulty or inability, the robot can read out the question statements. Apart from the statement, the projection displays four answer alternatives, and the child should place their hand over the chosen alternative for recognition.

Figure 14 showcases the game interface.

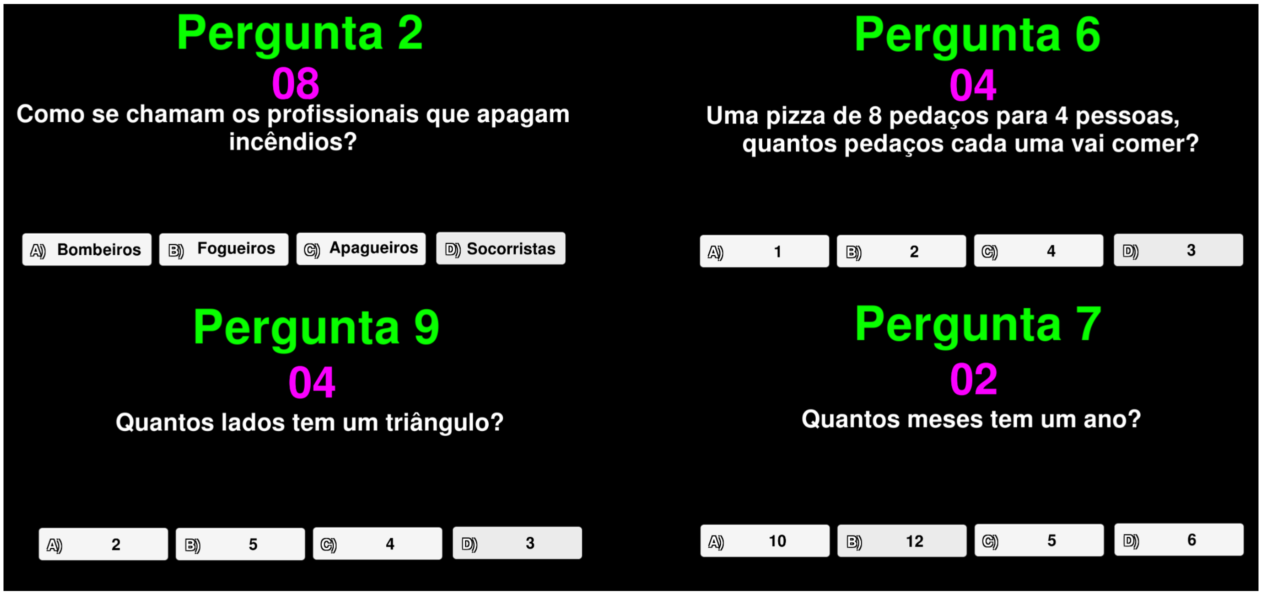


Figura 14 – Interface of Maria's Homework (in Portuguese)

At the end, the child's total score is displayed, along with the option to review mistakes, enabling the facilitator to guide and reinforce correct responses. Moreover, a textual report containing errors and correct answers with difficulty level and assessment area, as well as game execution time, is generated for facilitators' monitoring and evaluation.

4.4.6.1 Game's objective

This game aims to generate gains for children, therapists and family members, as listed below. Benefits for children with ASD are as follows:

- Engagement and motivation: The playful and interactive nature of the game helps maintain the interest and engagement of these children, making learning more enjoyable and stimulating.
- Development of cognitive skills: The game stimulates logical reasoning, problem-solving, memory, and critical thinking, promoting the cognitive development of children.
- Improvement of social skills: Interaction with the robot MARIA T21 provides a safe and controlled environment for children to practice social skills such as turn-taking, verbal expression, and non-verbal communication.
- Reinforcement of autonomy and independence: The game allows children to feel empowered and confident as they progress through difficulty levels and achieve their own accomplishments, promoting autonomy and independence.

- Encouragement of personalized learning: The DDA ensures that the game adapts to the individual needs of each child, providing a personalized learning environment and respecting each child's pace.

Applications by Therapists:

- Educational intervention: Therapists can incorporate the game "MARIA's Homework" into educational intervention sessions for children, using it as a complementary tool to teach and reinforce academic and social skills.
- Stimulating skill generalization: Therapists can use the game as an opportunity to work on the generalization of skills learned in therapeutic contexts, transferring them to real-world situations.
- Assessment and progress monitoring: The game offers therapists a way to assess and monitor the progress of children in different thematic areas, identifying strengths and areas that require more attention.

Applications by Parents and Caregivers:

- Reinforcement of learning at home: Parents can use the game as a complementary educational tool to support their children's academic learning at home, making the learning process more enjoyable and engaging.
- Encouragement of social interaction: The game provides an opportunity for parents and children to interact and engage in joint activities, promoting family connection and strengthening bonds.
- Progress monitoring: Parents can track their children's progress in the game, identifying areas where they may need additional support and providing positive and encouraging feedback.

4.4.6.2 Dynamic Difficulty Adjustment in this SG

One unique feature of the game is DDA (Figure 15). As the child progresses in the game, the next questions on the same subject are adjusted based on their previous performance. If the child answers correctly, the next questions may become more challenging. Otherwise, the game provides more accessible questions to avoid excessive frustration. This adaptive approach ensures that the game is suitable for the child's individual skill level, promoting their gradual progress and avoiding discouragement.

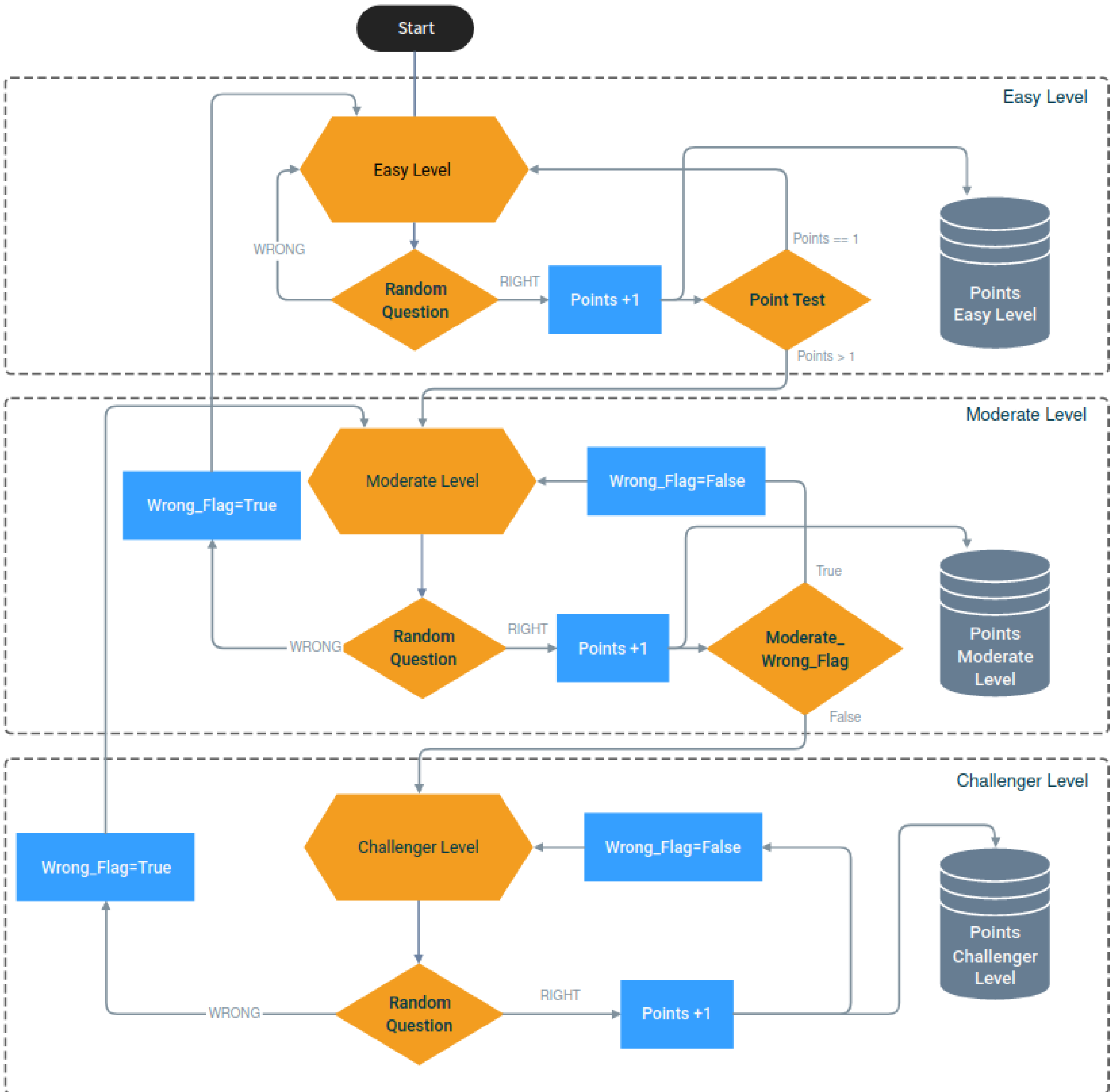


Figura 15 – Details of the DDA applied for the SG MARIA's Homework

4.5 Physical SGs

In this study, one SG was developed, evaluated, and validated, with an emphasis on the development of physical skills in different contexts. Despite this game is being focused on motor skills, there is always an interconnection and reinforcement of cognitive and functional abilities during their execution.

4.5.1 CrossKids

This SG is implemented by the SAR MARIA T21 through floor projection. The game initiates with the hopscotch, which constitutes the first stage of the circuit set. It consists of varying colors, numbers from 1 to 9, and a “finish” space that needs to be reached. Additionally, there are rules in the lower right corner of the projection that players must adhere to, specifying numbers to avoid on the path to the finish. The objective is to play hopscotch by hopping on one foot where there is a single square and using both feet where there are two squares – one foot on each square – while following the game’s requested rules. This involves unipodal support, jumps, and apraxia movements. Hopscotch is followed by others stages of training, that are as follow (Figure 16):

1. Characteristic pathway through pairs of circles alternating between closely spaced and more distant circles, requiring the child to jump with feet together and apart.
2. Path formed by colored squares arranged to resemble a pair of footprints, featuring varying directional orientations (forward, backward, right, and left). In addition to jumping, the child must perform controlled spins at specific angles around him/her axis.
3. Walking with the tip of one foot juxtaposed to the heel of the other foot along a straight-line projection.
4. Walking along a distinctive path projected as a sinuous line, maintaining the tip-to-heel alignment of the feet.
5. Jumping over footprint images while alternating between unipodal and bipodal support.
6. Stepping on randomly appearing balloon images within a specified time frame, with the aim of popping them. This involves agility absorption, displacement, muscular strength during jumping, response speed, and trunk rotation.
7. Walking with the tip of one foot juxtaposed to the heel of the other foot along curved lines.
8. Jumping onto an image of a disappearing pair of footprints upon being touched by the child’s feet, resulting in the appearance of another pair of footprints at a considerably challenging distance, with certain degrees of rotation relative to each other, forming a pathway.
9. Jumping whenever the projection of a rotating obstacle approaches the child’s feet, simulating the act of jumping over the object. Footprint orientation markings guide the child’s foot positioning during the jump.

The interaction between the robot and the child occurs through an algorithm that utilizes information provided by the LIDAR sensor. The point cloud obtained from the LIDAR needs to undergo filtration as the play area is delimited. Consequently, points obtained outside this area are discarded. After this initial filtering, it is assumed that only the child is within

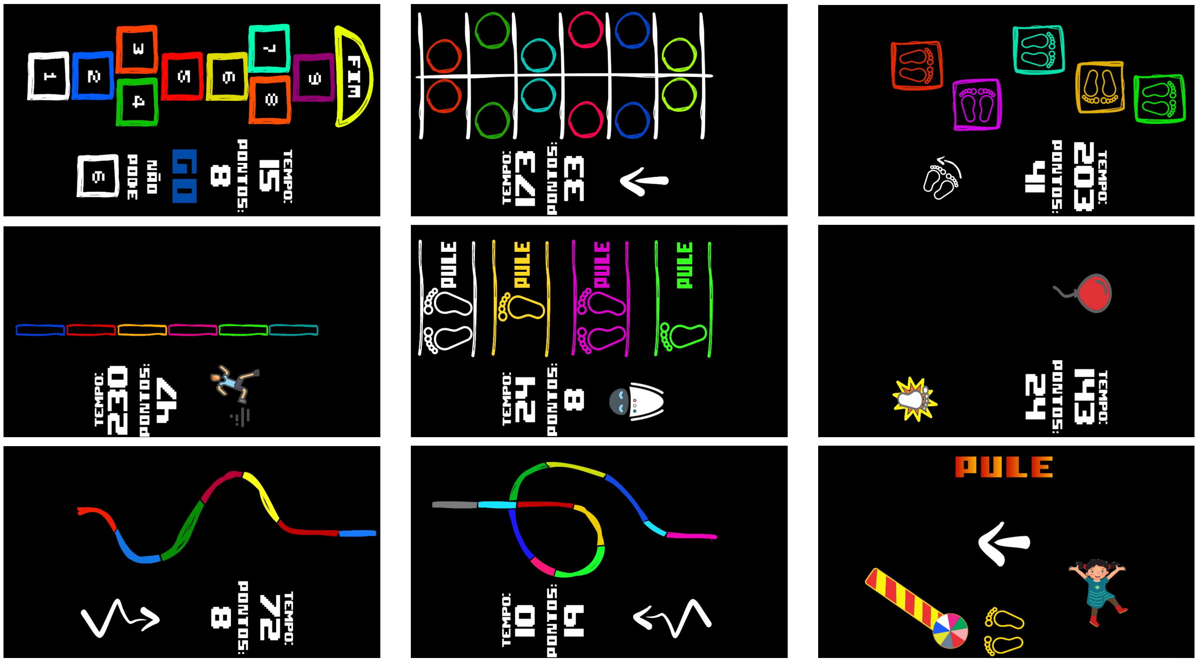


Figura 16 – Some of the circuits of the CrossKids (in Portuguese)

the play area. This assumption is validated when the remaining points exhibit a dispersion below a certain threshold. Accordingly, the child's continuous x and y positions are determined through averaging the filtered points.

With the child's position established, their trajectory is compared against the correct trajectory for each level of the game circuit. Consequently, if the child completes the trajectory accurately, they earn a point for each game element. These elements vary for each circuit, as depicted in Figure 16. Upon reaching the last element of a level, a new circuit is displayed. At the end of the game, the score and execution time are presented (Figure 17). Algorithm 4 conceptually outlines the described interaction algorithm.

Figura 17 – End of CrossKids (in Portuguese)

Algorithm 4 Assessment of level performance

```
Require: Child x, y position calculated by Algorithm 1
  if child_xy ∈ circuit_x,y then        ▷ Check if the child is performing the circuit correctly
      score + +
  end if
  if child_xy = circuit_x_end,y_end then        ▷ Check if the child is at the end of circuit
      if score > 70% then        ▷ Desired hit level
          challenge = True        ▷ Next challenge
      end if
      next_circuit()
  end if
Ensure: score
```

4.5.1.1 Game's objective

The overall objective of the SG CrossKids is to act as a playful, affective, adaptive therapeutic tool for exercise, development of motor skills in children with ASD. Specifically, it seeks to treat hypotonia, delayed motor development, difficulty with balance and motor coordination, joint hyperflexibility, apraxia, posture problems, low physical resistance and easy fatigue.

Functional Training Circuit is widely used as rehabilitation and physical conditioning therapies in children with some motor deficit. When such an intervention proposal is applied from the SAR MARIA T21, a significant gain is obtained to all the practicality generated by the infinite possibilities of projection, without the need for physical elements. In addition, through the system of emotions and speech, the robot is able to interact with the child, encouraging him/her and correcting any movement realized badly by the child (CHO; LEE, 2020; LI et al., 2020; PANCERI et al., 2021).

4.5.1.2 Dynamic Difficulty Adjustment in this SG

The circuit in this SG is composed of five basic types of challenges, which succeed each other sequentially. These challenges are the hopscotch stage, the stage of footsteps in various directions, the balloon stage, the tightrope walking stage, and the stage of jumping on circles with varying spacing. It is worth noting that, except for hopscotch, all the other stages of the circuit present different levels of difficulty.

In the Different Direction Footsteps challenge, players encounter a path formed by colored squares, each pair of footprints presenting various directions such as forward, backward, right, and left. Here, the challenge goes beyond the simple act of jumping; children also need to execute controlled spins at specific angles around their own axis. This is the easy version of the circuit. In the second encounter with this stage, which is classified as moderate in terms of difficulty, the direction of the footsteps not yet taken (i.e., those where they have not yet stepped) alternates every 3 s. In the third variation, the footsteps remain static but more challenging, requiring the child to perform jumps and attempt to land with the toes pointing in opposite directions while bringing the heels together. This represents the peak challenge in this circuit.

In the Easy Balloon challenge, the task involves stepping on randomly projected balloon images with the goal of popping them within a time limit. This stage requires agility, muscular strength in jumping, movement, response speed, and even trunk rotation. In the moderate challenge, on the second occasion, balloons disappear every 3 s if not popped. In the most challenging approach, balloons appear in motion in the projection, demanding quick responses and precise movements from the children.

As for the Tightrope Walking challenge, participants must walk with the tip of one foot juxtaposed to the other, following a straight line projected on the floor. This is the easy version of the challenge. In the second variation, considered moderate in terms of difficulty, the path includes sharper curves and even turns. In the third and final variation, the challenge reaches its peak complexity with a zigzagging path that increases difficulty by dealing with more pronounced curves.

Finally, in the Open and Closed Circles challenge, players encounter a path characterized by alternating pairs of closely spaced and widely spaced circles. Here, children need to alternate between jumping with feet together and feet apart. In the moderate version, a change in the longitudinal distance between the circles is introduced, simulating wider strides. In the third variation, the challenge increases by presenting a projection with multiple circles, resembling a Swiss cheese. In this variation, children need to choose which circles to jump on to reach the other side, where the circles already stepped on remain fixed, while the others change position every 3 s. Figure 18 presents the CrossKids DDA scheme and sequence of stage types in this SG.

If a child does not achieve a satisfactory result in the moderate level of one of the circuits, for instance, the next time this type of circuit is presented, it will again be at the moderate level. This phase scheme offers a gradual progression of difficulty, interspersed with moments of rest using the hopscotch phase.

The development of this SG has led to the publication of a paper at the XII Ibero-American Congress on Assistive Technologies for Disabilities 2023 (PANCERI et al., 2023; SCHREIDER et al., 2023).

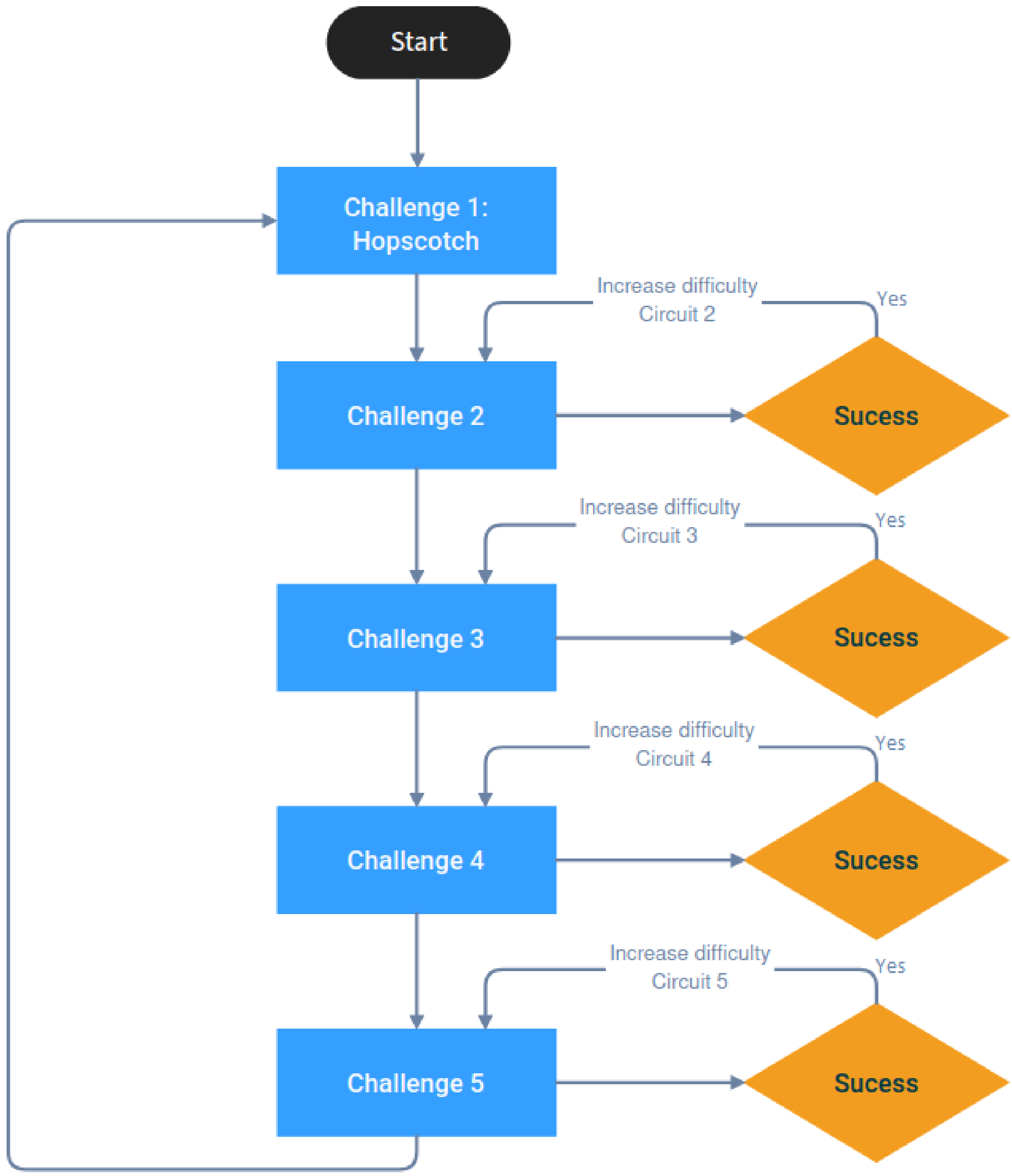


Figura 18 – Details of the DDA applied for the SG CrossKids

4.6 Functional SGs

More accurate and culturally sensitive screening approaches are needed for children with ASD. For that, shared decision-making requires collaboration with families in the assessment and selection of interventions (HYMAN et al., 2020).

The development of skills has been gaining increasing attention, as opposed to a continuous focus on reducing challenging behaviors. While the latter issue is of great importance, many interventions are available to address these problems at this point. Furthermore, it is becoming increasingly evident that improving pro-social skills results in competitive responses to challenging behaviors and, therefore, to some extent, it is useful in reducing the frequency and intensity of problem behavior (MATSON et al., 2012).

The following are the SGs and dynamics developed and employed in this study through MARIA T21. Despite these games being focused on ADLs, there is always an interconnection and reinforcement of cognitive and motor functions during their execution.

4.6.1 Raining food

The game Raining Food is divided into six stages that represent meals throughout the day: breakfast, mid-morning snack, lunch, afternoon snack, dinner, and supper. The game operates within the functional domain of SG in MARIA T21 and contributes to the development of ADLs.

The mechanisms of all stages are the same and consist of an avatar that moves from left to right while food falls. The player must collect the foods taught by the therapist for the respective meal, avoiding unhealthy or inappropriate foods.

Each stage begins with the projection of a plate containing the meal's foods and their names for 30 s. During this time, the therapist introduces the children to the foods, the meal, the recommended time, and other relevant instructions. Following the explanation, a timer is displayed alongside the meal's name, allowing the player to collect the foods within the stipulated time.

In case there are doubts or forgetfulness about which foods should be collected, the child can refer to the foods in the right corner of the projected plate to recall the task. Additionally, there is a bin in the lower left corner of the screen, enabling the child to discard incorrect foods and restart the collection (Figure 19).

4.6.1.1 Game's objective

The main objective of Raining Food is to teach healthy and appropriate eating habits for each age group, stimulating the adoption of a balanced and varied diet since childhood. Some specific objectives included in the action of this SG, focused on food education for children, may include:

- Promoting the consumption of nutritious foods: Teaching children the importance of including in their daily diet foods rich in essential nutrients, such as fruits, vegetables,

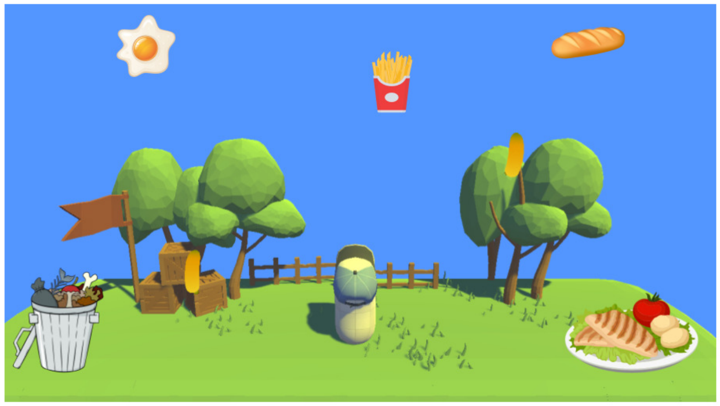


Figura 19 – Interface of the SG Raining Food

lean proteins, and whole grains;

- Preventing diseases: Guiding children about the relationship between diet and health, showing them how the proper choice of foods can prevent diseases and improve the body's functioning.
- Developing healthy eating habits: Encouraging the development of healthy eating habits, such as making conscious food choices, eating slowly, and chewing food well.
- Raising awareness about the impact of food on the environment: Teaching children the importance of choosing sustainable foods that respect the environment and contribute to the preservation of natural resources.
- Promoting family meals: Encouraging children's participation in meal planning and preparation, as well as promoting the practice of family meals, which can improve the quality and variety of food and strengthen family bonds.
- Preventing childhood obesity: Alerting about the risks of childhood obesity and encouraging the adoption of a healthy lifestyle, with regular physical activity and a balanced diet.

4.6.1.2 Dynamic Difficulty Adjustment in this SG

In this SG, DDA is achieved through the modulation of the speed of food appearance, time for task completion, and variety of products (foods) displayed, such as shown in Figure 20.

If the player performs below standard, such as taking too much time in the previous stage or collecting many incorrect foods, the falling speed of the items is reduced, or the variety of foods is decreased to facilitate the task. Conversely, if the player performs well, the speed is increased, or the food variety expands to enhance the challenge.

The modulation mechanism is similar across all these stages, with adjustments based

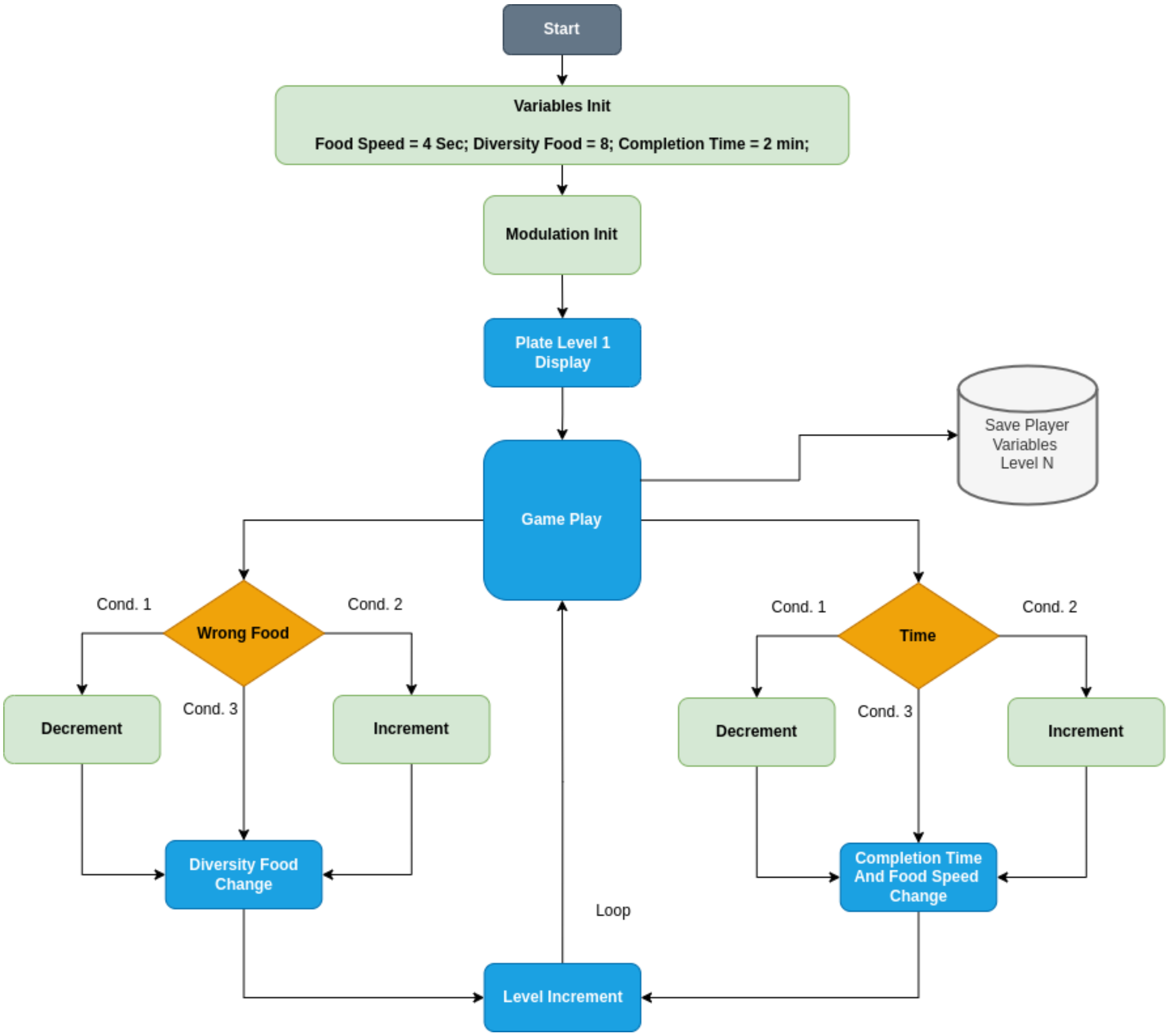


Figura 20 – Details of the DDA applied for the SG Raining Food

on the performance of the previous stage:

- If the time spent in the previous stage exceeds 2 min (reaching the stage limit), the falling speed of the items is decreased by 0.3 s (Change A).
- If the time spent in the previous stage is less than 1 min, the falling speed of the items is increased by 0.3 s (Change B).
- If the time spent in the previous stage falls between 1 and 2 min, the falling speed of the items remains the same as the previous stage (Change C).
- If the number of incorrect foods collected is greater than 8, the number of types of foods that fall is reduced by 1 (Change D).
- If the number of incorrect foods collected is fewer than 4, the number of types of foods that fall is increased by 2 (Change E).

- If the number of incorrect foods collected falls between 4 and 8, the variety of foods remains the same as the previous stage (Change F).

This tree of changes allows for personalized adjustments for each player, aiming to enhance their skills and knowledge related to healthy eating. The recording of information in the text file at the end of each stage enables professionals to assess the player's progress and adapt the modulation to meet their specific needs.

The development of this SG has led to the publication of a paper at the XII Ibero-American Congress on Assistive Technologies for Disabilities 2023 (FREITAS et al., 2023).

4.6.2 Bricks Breaker

This SG consists of 64 static bricks represented by pink rectangles, a red ball that moves according to the angle at which it makes contact with the contact surfaces present in the game, and a blue platform where the child must position himself/herself and use it as a lower contact surface that prevents the ball from leaving the field of view. The bricks that come into contact with the ball are collected and add speed to it.

Despite requiring motor movements for control, this game was developed as a simulator for practicing spatial and geometric reasoning to gain benefits in everyday activities and subsequent gains in autonomy. By calculating trajectories and angles to hit specific bricks, children can develop their spatial and geometric reasoning skills, which are important for solving everyday problems involving the positioning and movement of objects. Figure 21 shows the interface of the game Bricks Breaker.

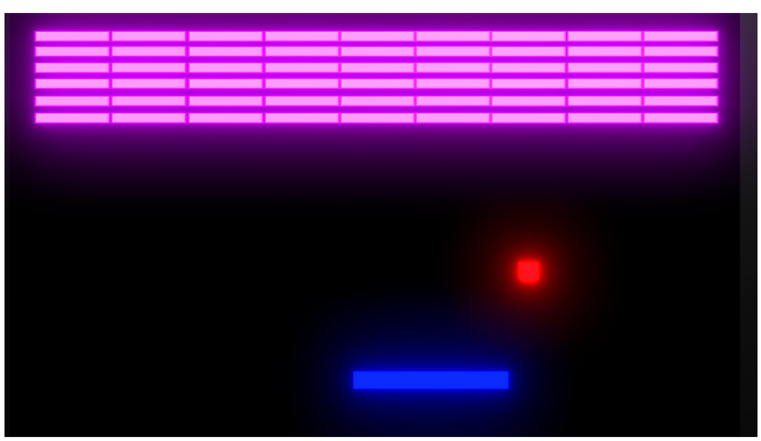


Figura 21 – Interface of the SG Bricks Breaker

This SG also requires children to focus on the ball, bricks, and platform throughout the game to avoid losing lives and effectively collect the bricks. This practice can aid in the development of sustained attention, which is crucial in various daily activities such as learning, following instructions, and completing tasks.

Furthermore, as children face challenges in the game and deal with the frustration of losing lives, they have the opportunity to develop skills to resolve internal conflicts and regulate their emotions. These skills can be transferred to everyday situations that require emotional control and problem-solving.

4.6.2.1 Game's objective

The general objective of this SG, developed to be used as an occupational therapy activity for children with ASD, is to promote the development of functional everyday skills through the exploration of the concepts of time/velocity and space. Through the application of ABA delivered by the SAR MARIA T21, the game aims to provide an interactive and personalized experience, adapting to each child's individual performance, addressing cognitive, motor, and emotional skills, such as concentration, sustained attention, spatial reasoning, bilateral coordination, planning, strategy, emotional regulation, self-control, and quick decision-making. Additionally, it aims to develop visual and spatial perception, fine motor skills, social skills in interacting with the robot MARIA T21, and the transfer of learned skills to daily life situations, such as crossing a street safely.

4.6.2.2 Dynamic Difficulty Adjustment in this SG

Initially, the game starts with five lives and operates in a standard mode without any difficulty modulation. Every four collected bricks, the ball's speed (in unit of speed of Unity) slightly increases, creating an initial challenge for the child.

However, as the children progress, the game begins to modulate the difficulty based on their performance. If the child reaches three lives without collecting ten bricks, the ball's speed is decreased by a ratio of $X/4$ (where X is the speed of the ball). This provides the child with more time to react and make decisions, making the game more accessible for those who are still adapting to the game dynamics.

If, even with the reduced speed, the child still loses lives before collecting sixteen bricks, the platform's width is increased by two units. This change helps to provide a larger area for platform control, facilitating movement and allowing greater stability. Losing lives does not reset the total bricks; it only recovers 10 bricks for each life lost.

On the other hand, if the child reaches six lives (one life is gained whenever the player collects 16 bricks in a row) without losing any previously, the value of X is increased by

20%. This intensifies the challenge for children who have shown good initial performance, promoting continuous skill improvement.

However, even with the increase in X, if the child achieves seven lives (meaning, collecting thirty-two bricks), the platform's width is reduced by two units. This reduction creates an additional challenge for children who have demonstrated a high level of skill and control in the game, encouraging constant pushing of limits. Figure 22 presents the operational scheme of the DDA in this SG.

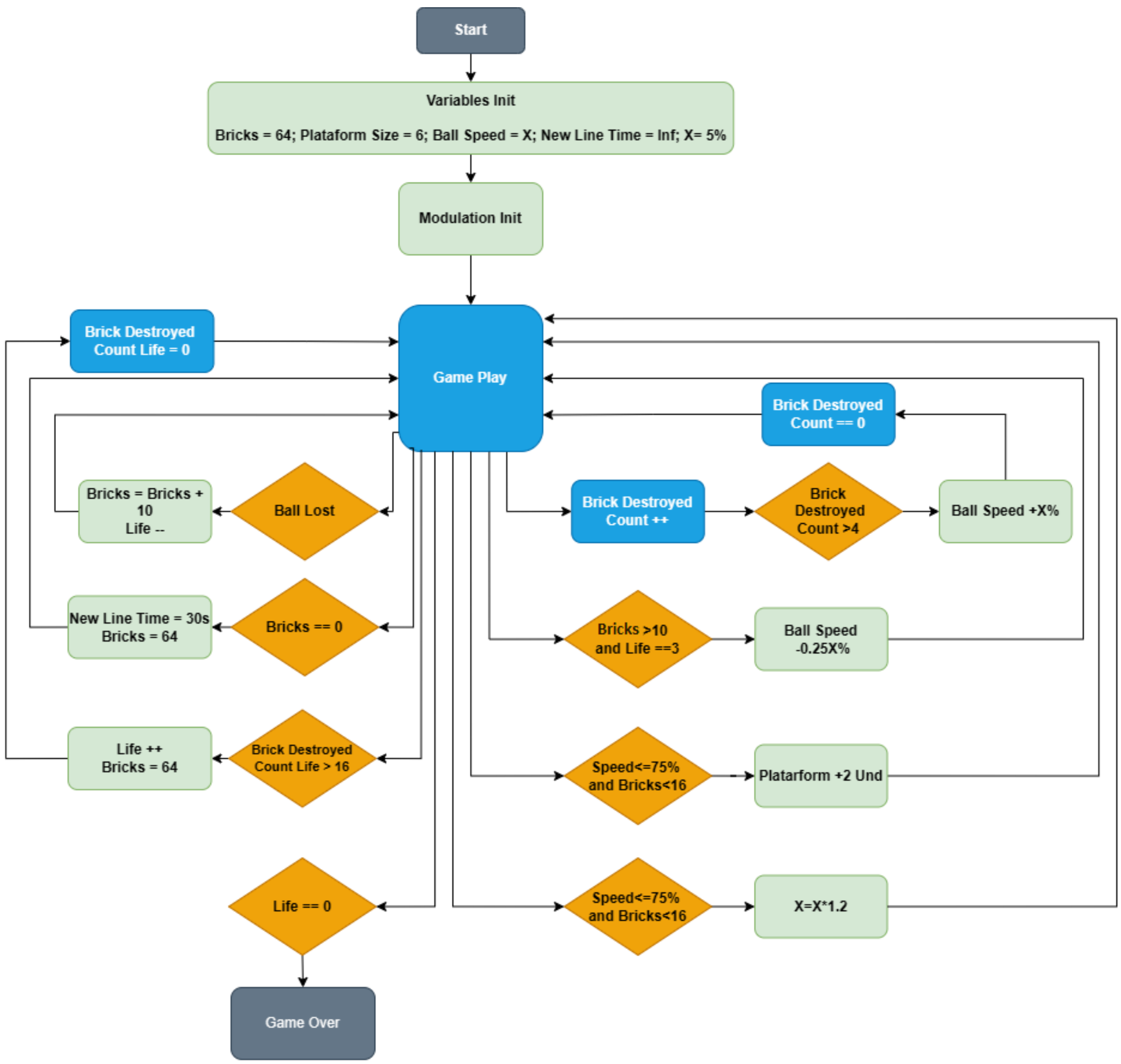


Figura 22 – Details of the DDA applied for the SG Bricks Breaker

If the child manages to complete all 64 bricks, the game resets everything, changes the color of the bricks and the background, and advances to a final stage where a new layer of bricks appears every thirty seconds. This radical change creates a new level of difficulty for more advanced players, motivating them to continue refining their skills.

Throughout the game, crucial information about the child's performance is recorded in a text file at the end of the session. This report includes the total execution time, the recorded speed whenever a life is lost, the total collected bricks, platform size, and the number of lives gained. This record enables professionals to assess the child's progress over time and adjust the challenge level to meet individual needs.

With this DDA system, the game Bricks Breaker becomes a valuable tool for occupational therapy for children with ASD. It provides an interactive and engaging environment to develop functional skills such as time/speed and spatial awareness, concentration, coordination, planning, emotional regulation, and much more. Moreover, the use of the SAR MARIA T21 as an interaction medium makes the experience even more captivating and socially enriching.

4.6.3 Dynamics

Regarding functional skills, some dynamics were added to the protocol under the guidance of an Occupational Therapist. These dynamics were not categorized as SG and did not involve dynamic modulation. However, they were applied using the robot, with step-by-step guidance, encouragement, and corrections, following the principles of the ABA DTT methodology. Table 3 presents the four main groups of prompts used during the execution of the dynamics and their respective utterances.

The development and application of this dynamics has led to the publication of a paper at the XII Ibero-American Congress on Assistive Technologies for Disabilities 2023 (MACIEL et al., 2023).

4.6.3.1 Tracing

In this activity, the robot MARIA T21 projects a variety of drawings onto a table, including some simpler ones, composed of few straight lines, and others with more details, making them more complex. The child receives glitter glues and pens of various colors and is instructed to use these materials to trace over the projected drawings. When using the glue, children need to exert constant and controlled pressure to deposit it in the desired areas. Figure 23 shows some of the drawings used in this activity.

Tracing is an activity particularly beneficial for the development of fine motor coordination of the hands and fingers, an essential skill for tasks such as writing, drawing, tying shoelaces, and manipulating small objects. Moreover, it works on various other important skills for child development, such as the pincer grasp, needed to hold and control small objects

Table 3 – Prompts used during the execution of the dynamics

Encouragement Phrases	• You're doing a great job! Keep it up! • I believe in you! I'm sure you can do it! • Wow, you're doing really well! I'm impressed! • I'm here to support you every step of the way. Let's do this together! • Keep trying, practice makes perfect!
Praise Phrases	• Congratulations on your effort and dedication! You're amazing! • Incredible! You did a wonderful job! • I'm so proud of you! Congratulations on your achievements! • Congratulations, keep it up! You're making great progress! • Your efforts are paying off, keep going!
Correction Phrases	• Don't worry about mistakes, we all learn from them. • Let's try again together, I'm here to help you. • Making mistakes is normal, the important thing is to learn and improve. • Don't be afraid to make mistakes, that's how we grow and learn. • You're putting in effort, and that's what matters! Let's try again!
Guidance Phrases	• Pay attention to the details to get it perfectly. • If you have any questions, you can ask me! I'm here to help. • Take a deep breath and take it easy, you can do it very well! • Pay attention to what the teacher is saying, let's learn how it's done. • Trust yourself, you have all the necessary skills.

with the index finger and thumb, and the ability to concentrate and pay attention while tracing the lines of the projected drawings (ZHANG et al., 2022).

The activity also stimulates creativity and imagination, allowing children to express their art by drawing over the projections with different colors. Additionally, the cognitive process involved in recognizing shapes, colors, and patterns contributes to the development of cognitive thinking and visual perception. The interaction with the robot during the activity provides an interactive and playful experience, encouraging social interaction and assisting children who may face difficulties in this aspect. As children practice and improve their skills, they develop greater self-esteem and self-confidence, as the sense of achievement upon

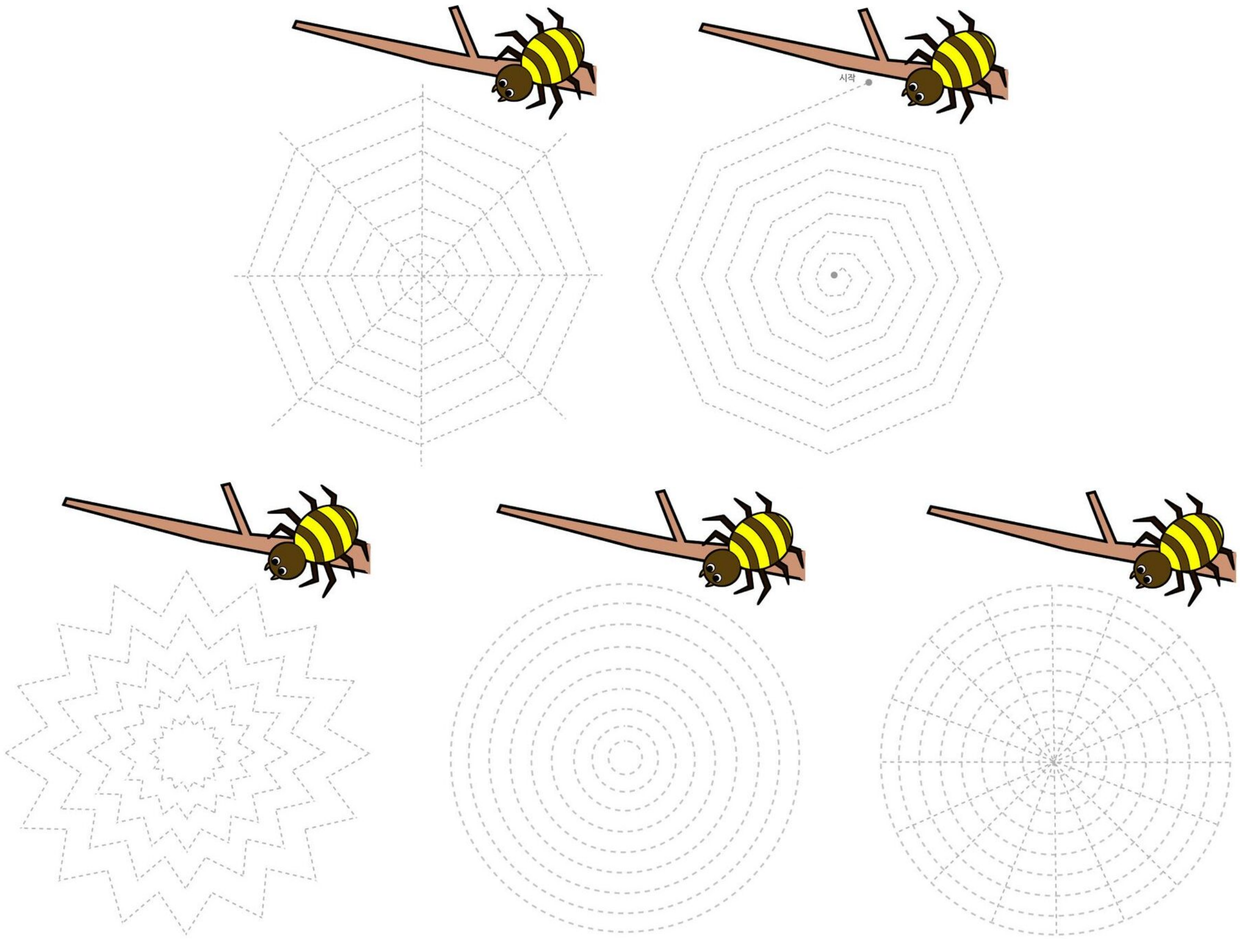


Figura 23 – Some drawings of dynamic tracing

completing the drawings promotes a feeling of accomplishment. Furthermore, the activity can serve as a form of sensory therapy as it involves the use of different materials, such as pencils and glitter glue, providing various tactile stimuli, which can be particularly beneficial for children with sensory difficulties (SHAFIE, 2022). Figure 24 shows a child performing this dynamic.

In addition to the mentioned benefits, this activity can be adapted to meet the specific needs and interests of each child, making it a valuable tool for therapeutic progress and active engagement of children in their own therapy.

4.6.3.2 Super Hero

The Super Hero occupational therapy activity is a creative and playful approach to work on various important skills in children. This activity involves not only the act of putting on the cape itself, but also interacting with the robot, which can make the process more fun and engaging for the children. To carry out this activity, at the beginning of the therapy,

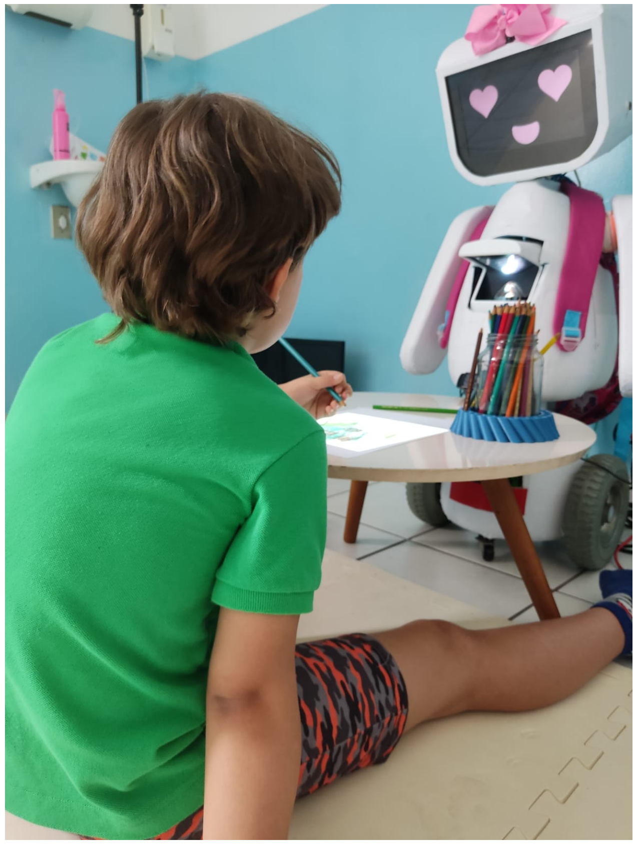


Figura 24 – Child doing dynamic tracing

the children are asked to put the capes on themselves and on MARIA T21, and at the end, they are asked to take them off. Putting on the capes required the child to tie bows with the ribbons, and to remove them, as they had to untie the bows. Figure 25 shows the execution of the Super Hero dynamics with the help of the therapist while the SAR provided guidance and praise according to the ABA methodology of DTT type.

In addition to the main objective of teaching tying knots and promoting independence in the dressing process, it is believed that this activity can bring several other therapeutic benefits, such as:

- Fine motor coordination: When putting the superhero cape on, children need to use their fine motor coordination skills to manipulate the knots and secure the cape around their neck. This movement requires dexterity and precision in the hands and fingers, which can be especially helpful for children who need to improve these skills (ISBELL, 2010).
- Enhancement of proprioception: This activity involves the manipulation of objects, such as the cape and knots, which can help children develop a greater body awareness and proprioception. This skill is essential for children to move safely and confidently in their

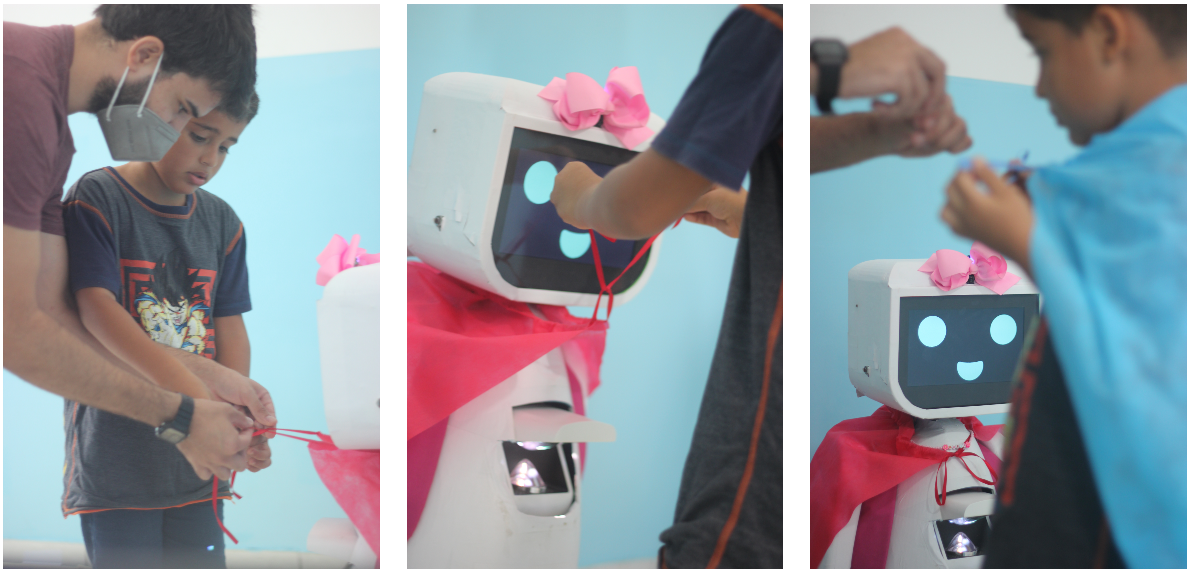


Figura 25 – Dynamic super hero

environment (KURTZ, 2014).

- Stimulus for creativity and imagination: By interacting with the robot and engaging in the activity of dressing up as a superhero, children are stimulated to use their imagination and creativity. This can aid in the development of creative expression and the ability to solve problems innovatively.
- Language and communication development: During this activity, children receive guidance and stimuli from MARIA T21 and can engage in conversations with therapists about the cape, the robot, and superheroes. This verbal interaction can aid in language development and improvement of communication skills.
- Strengthening of self-esteem: When dressing up as superheroes, children may feel more confident and empowered, which can strengthen their self-esteem and self-confidence, even during the execution of SGs.
- Encouragement of teamwork: The involvement of the child and therapists can provide an opportunity to work as a team and develop social skills such as sharing, cooperating, and respecting others' space (D'AMICO; LALONDE, 2017).
- Reduction of stress and anxiety: The playful and fun environment of this activity can help reduce children's stress and anxiety, making the experimental protocol more enjoyable and less intimidating (HANH, 2007).

5 Experimental Protocols

5.1 Preliminary Experiment

The Association of Friends of Autistic People of Espirito Santo (in Portuguese AMAES) in Vitoria and the APAE of Vila Velha were the chosen settings for conducting the preliminary experiment involving children with ASD and SGs. This experiment served as an evaluation of the developed SGs up to that point, identifying demands, adjustment needs, and reinforcing the hypothesis of the necessity for personalized therapy for each child. The aim of this chapter is to present the methodology used, starting from the selection of participating children to the conduction of sessions with MARIA T21.

5.1.1 Scenario

The sessions were conducted at the respective AMAES and APAE Vila Velha facilities, in rooms with low light incidence to facilitate the projection of the SGs. Due to limitations of the institutions, there was no fixed and exclusive space for the protocol, and, therefore, MARIA T21 was moved to other rooms as per availability. However, the adopted layout followed the configuration shown in Figure 26.

5.1.2 Participants

The children with ASD eligible to participate in this study were selected by the psychology professionals from AMAES and APAE Vila Velha, based on the following inclusion criteria:

- Children diagnosed with ASD (level 1/mild or 2/moderate), according to DSM-5 criteria, and/or diagnosed with Childhood Autism;
- Age range from 6 to 13 years;
- Ability to comprehend verbal and/or visual commands during games and interventions;
- Absence of traumatic experiences or phobias.

On the other hand, the exclusion criteria comprised children with:

- Concomitant neurological disorders, such as epilepsy or syndromes affecting brain development;
- Excessive stereotyped/repetitive movements;
- Tendency towards aggression and/or being highly agitated.

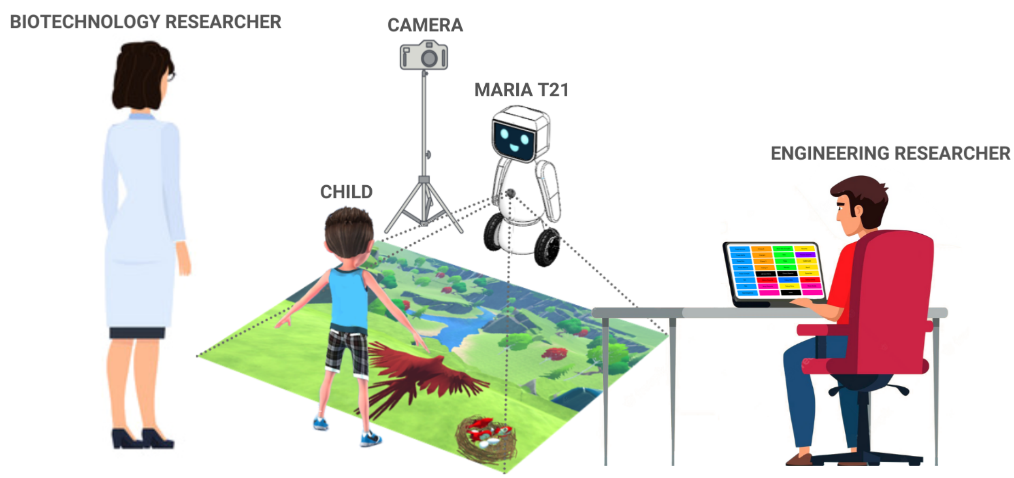


Figura 26 – Layout of the interaction room in the preliminary experiment

The parents and guardians of these children were contacted to conduct a detailed anamnesis about their children's life and development. Additionally, they were informed about the research, its objectives, and protocols. To ensure the ethics and legality of the study, the Informed Consent Form (ICF) was presented. This document is essential to ensure voluntary and conscious participation of the children in the research. Table 4 presents the profile of the participants.

After obtaining parental consent, the children underwent assessments using publicly available tests. These assessments aimed to measure important characteristics for the research and the development of the SGs.

5.1.3 Procedure

The protocol was applied in a period of three months and consisted of 10 sessions at AMAES and 4 sessions at APAE Vila Velha, each lasting approximately 45 min. Throughout the sessions, all COVID-19 prevention measures were strictly adhered to, including the use of masks and constant hand sanitization, since they happened in the second half of 2021.

During the first session, the robot MARIA T21 was introduced to the children. It introduced itself, asked the child's name, and inquired about their interests. The robot then invited the child to play, and in case of any resistance, the researchers intervened, encouraging the child to participate. Subsequent sessions always began with a warm greeting from the

Table 4 – Profile of participants in the preliminary experiment

AMAES Participants	Sex	Age	Level
C1	Male	13	Mild
C2	Female	12	Mild
C3	Male	12	Mild
C4	Male	10	Mild
C5	Male	8	Mild
C6	Female	8	Mild
C7	Male	8	Mild
APAE Participants	**Sex**	**Age**	**Level**
C8	Male	9	Mild
C9	Male	8	Mild
C10	Male	6	Mild
C11	Female	6	Mild

robot, followed by a request for a hug and a guided stretching exercise led by MARIA T21. The sessions proceeded with the execution of the following SGs (in their beta versions): CrossKids, Memo, Hungry Bird, and Raining Food. The sequence of execution was consistent across all ten sessions.

Before each game, the researchers explained and demonstrated the correct way to play to the child. Throughout the interactions, the researchers provided assistance to the children as needed, using verbal commands to guide them. At the end of the games, the children were praised and encouraged to do stretching exercises.

After the conclusion of the protocol, the children were reevaluated using the same tests applied at the beginning of the research. Additionally, interviews were conducted with the parents and guardians to identify positive aspects observed in the children's interactions with the robot.

The attending psychologists were also interviewed to gather information about the positive points of the research and provide suggestions for improvements in the games and in the protocol.

5.1.4 Rating scales

In this study, there is no control condition, as is common in ASD studies, because individuals with ASD exhibit an extremely wide range of symptoms, combinations of symptoms, and severity of symptoms. Consequently, working with participants with ASD typically follows a single-case study design instead of a randomized study design. In this study, in addition to the data produced by the SAR technology, the following scales were also employed:

1. Cancellation Attention Test (TAC for its acronym in Portuguese): Assesses aspects of selective and alternating attention (MONTIEL; SEABRA, 2012). The test consists of three parts, in which the task is to mark on the printed matrices the stimuli identical to a previously determined target. The child has one minute to mark the figures in each task, following the order of the 15 lines in the matrix, each with 20 geometric figures (circle, square, triangle, cross, star, and dash). The performance on the test is scored separately for each of its three parts, considering the total number of stimuli correctly marked by the child.
2. Trail Making Test (TMT): Specifically designed to evaluate cognitive flexibility, which refers to the ability to adapt cognitive processing strategies, changing thoughts or actions, in accordance with new situations (TREVISAN; SEABRA, 2012). Attention, visual search, cognitive flexibility, and speed are mobilized. As performance measures, the number of correct sequences in parts A and B of the test was used.
3. System Usability Scale (SUS): It was used to assess system usability. It allows professionals and parents or caregivers to evaluate the ease of use of the robot and SGs as a therapeutic tool for children with ASD (LEWIS; SAURO, 2009; BROOKE, 2013).
4. Goal Attainment Scaling (GAS): It is an evaluative approach that quantifies individuals' progress towards personalized objectives. Widely employed in healthcare, education, and social services, it facilitates the establishment of measurable goals for each individual, proving valuable for those with diverse objectives and varied responses to interventions. GAS acknowledges that success is not merely binary – achieved or not achieved – but rather focuses on the degree of attainment (TURNER-STOKES, 2009; KRASNY-PACINI et al., 2013).
5. Fonseca's Psychomotor Battery: Comprising various tasks and tests that encompass different psychomotor skills and competencies, such as motor coordination, balance, laterality, body schema, and spatial-temporal organization, this battery aims to analyze psychomotor development and identify potential difficulties or alterations in this area in children, adolescents, and adults. It is particularly applied in clinical, educational, and research contexts (FONSECA, 1995).

5.2 Advanced Experiment

5.2.1 Participants

Eighteen children diagnosed with ASD in mild (level 1) to moderate (level 2) ranges, as described in the DSM-5, were included in this research, referred to only as K1-K18. The families were recruited, at that time, at the APAE in Vitoria, Espirito Santo (Brazil). A presentation of the study was made to the institution's management and then an initial screening of the participants was conducted by a licensed Occupational Therapist who reviewed each child's developmental and health information to match the study's inclusion criteria:

- Diagnosis according to DSM-5 for ASD (levels 1 and 2);
- Age between 5 and 9 years old;
- Both genders;
- Eye and/or hand and/or foot and/or echolalia stereotypies.

Families interested in participating in the research contacted the research team and provided written information about their child with ASD through a questionnaire-style anamnesis that allowed the researchers to have prior knowledge of the children's main deficits and adverse behaviors. Table 5 presents the profile of the participants.

Table 5 – Profile of participants in the Advanced Experiment

Participant	Sex	Age	Stereotype	Level
K1	Male	7	Hand Flapping, Toe Walking, Echolalia	Moderate
K2	Female	8	Toe Walking	Mild
K3	Male	9	Toe Walking, Echolalia	Mild
K4	Male	7	Toe Walking, Avoidance of eye contact	Moderate/Severe
K5	Female	6	Toe Walking, Echolalia	Mild
K6	Male	6	Hand Flapping, Echolalia	Moderate
K7	Male	8	Toe Walking, Echolalia	Moderate
K8	Male	7	Toe Walking, Echolalia, Av. of eye cont.	Moderate
K9	Female	7	Echolalia, Avoidance of eye contact	Moderate
K10	Male	6	Toe Walking, Echolalia	Moderate
K11	Male	7	Echolalia	Mild/Moderate
K12	Male	7	Toe Walking	Mild
K13	Male	6	Hand Flapping, Toe Walking	Mild/Moderate
K14	Male	6	Toe Walking	Mild/Moderate
K15	Male	7	Echolalia, Avoidance of eye contact	Moderate/Severe
K16	Male	7	Avoidance of eye contact	Mild/High Skills
K17	Male	7	Toe Walking, Avoidance of eye contact	Mild
K18	Male	9	Non-verbal, Hand Flapping	Moderate/Severe

Before starting the intervention, written ICF was obtained from the guardians of the participants.

5.2.2 Scenario

The intervention took place in a therapy room approximately 5 m x 6 m in size, with an EVA (Ethylene Vinyl Acetate) mat flooring. The room had a table and two chairs, where one researcher controlled the SAR actions during the intervention and collected performance data to ensure interobserver reliability, while another mediated the child-robot interactions. MARIA T21 was placed at one end of the room, near a wall, so that its cameras could record a larger angle and there would be enough space for the SGs projections on the floor. Figure 27 shows the employed layout.

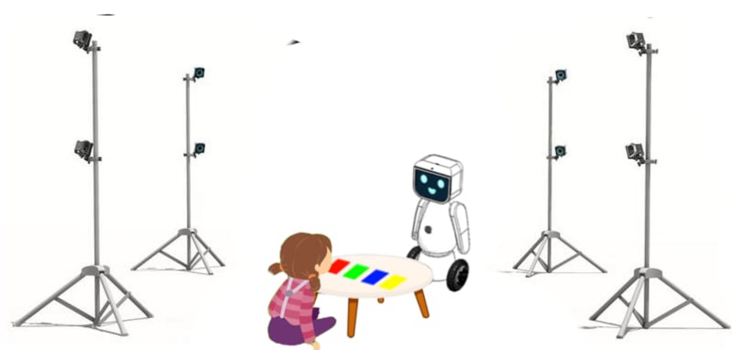


Figura 27 – Layout of the interaction room in the advanced experiment

The camera mounted on the top of the MARIA T21 recorded a frontal view of the participating child with a focus on the face and upper limbs. A second camera positioned at its base recorded details of the lower limbs and, when distant, the full view of the subject's body. Four other cameras positioned strategically recorded the child-robot interaction from four side angles. All interactions were recorded. User engagement was noted through camera data analysis. A participant was considered engaged when he/she paid full attention to the interaction, promptly responding to the robot's requests or seeking further guidance or feedback from others in the room.

5.2.3 Procedure

The intervention was carried out over a 3-month period, with each child participating in a 45-minute intervention session once a week in the morning shift. The length of each session varied depending on the performance and preferences of the participants.

The session planning was done on a weekly basis. The researchers chose the level of prompts provided by the MARIA T21 to be used for the therapy session each week, which, in addition to the guidance and stimuli, contained diverse subjects to promote and encourage interaction. The choice of level was based on the child's performance in previous sessions. During each intervention session, a researcher used a screen with 20 buttons to control the robot's actions (Figure 28). These actions included:

- Weekly sequential prompts;
- Control of facial expressions;
- Reinforcing a correct response;
- Correcting an incorrect response;
- Requesting affection;
- Arm movements;
- Head movements;
- Initiating and terminating the SGs.

Figura 28 – Buttons to control robot's actions (in Portuguese)

The prompts were organized in a sequential manner, so the researcher used the greeting action for the robot to greet the child at the beginning of the session. Then, by activating the same button again, a sequential information was given. The researcher intercalated between the various command options to make the interaction as fluid and personal as possible. The interaction script containing the robot's speeches and the applicators' performances in the first week is presented below. The repetition of letters is purposeful, and aims to keep the nuances as faithful as possible from the prompts and original lines in Portuguese after the translation into English.

1. **Robot MARIA T21:** Gooood morniiing! I am soooo happy to meet you that I would juuump ten times if my wheels were not sooo heavy. But look how my eyes shine when I see you!
2. *Professional Applicator:* (*Guidance from the applicators for the child to notice the robot's facial expression*)
3. **Robot MARIA T21:** My name is MARIA, and I want to be your robotic friend. How about being friends?
4. *Professional Applicator:*(*Guidance from the applicators for the child to respond to the friendship invitation*)
5. **Robot MARIA T21:** Great! But tell me your name and how old you are!
6. *Professional Applicator:*(*Guidance from the applicators for the child to respond to the question*)
7. **Robot MARIA T21:** *CHILD'S NAME*, what a beautiful name, I loved it!
8. **Robot MARIA T21:** I am 10 years old and I like to go to the robot school to learn about nature. I also like to play little games, dance, and make friends like you. And you, what do you like to do? Tell me!
9. *Professional Applicator:*(*Guidance from the applicators for the child to respond to the request*)
10. **Robot MARIA T21:** That's cool! I want to know more about you and everything you like to do and play. So, can we play a little every week, what do you think? Would you like to come here to play and talk with me a little sometimes?
11. *Professional Applicator:*(*Guidance from the applicators for the child to respond to the request*)
12. **Robot MARIA T21:** YAAAAY. I am sooo happy to heaar that!
13. **Robot MARIA T21:** NOOOO. Don't say that, it makes me saad. Pleaasee.
14. *Professional Applicator:*(*Invitation to SG 1*)
15. *Professional Applicator:*(*Random phrases for correction, encouragement, and guidance during the game*)
16. *Professional Applicator:*(*Invitation to SG 2*)
17. *Professional Applicator:*(*Random phrases for correction, encouragement, and guidance during the game*)
18. *Professional Applicator:*(*Invitation to SG 3*)
19. *Professional Applicator:*(*Random phrases for correction, encouragement, and guidance during the game*)
20. *Professional Applicator:*(*Invitation to SG 4*)

21. **Robot MARIA T21:** Thank you for coming to visit me today. How about a goodbye hug?
22. **Robot MARIA T21:** What a lovely hug!
23. **Robot MARIA T21:** Put your shoe on and be careful. Digital kisses!
24. **Robot MARIA T21:** Tchau, Bye Bye, Adios!

If the child correctly answered some of the SG challenges or responded to a SAR dialogue in a desirable manner, the researcher controlled the robot to reinforce the child with a congratulation or social praise (buttons in Portuguese “Frases de acerto” and “Frases Afetivas”). In the case of a child responding to the dialogues, the researcher made use of the robot’s facial expressions to convey feelings and captivate the child’s attention through the promotion of empathy. If the child answered the SGs tasks incorrectly, the researcher controlled the robot to correct the child and encourage him/her (button in Portuguese “Frases de correção”).

During robot-mediated interventions, a researcher controlled the robot’s actions during the intervention and collected performance data to ensure interobserver reliability. To successfully control the robot’s actions during the intervention, the researcher controlling the robot was always able to see and hear the child.

5.2.4 Rating scales

In this experiment, in addition to the data produced by the SAR technology and the images from the cameras in the room, the CAT, TMT, GAS and Pediatric Evaluation of Disability Inventory Computer Adaptive Test (PEDI-CAT) scales were applied before the therapy sessions.

1. PEDI-CAT: Developed with innovative measurement methodologies, it assesses the functionality of children and youth, ranging from 0 to 21 years old, with different health conditions (MANCINI et al., 2016).

In the Advanced Experiment, the scales were applied only prior to the protocol with the purpose of assessing the participants’ cognitive, physical, and functional conditions. These scales are well-established tools widely used in clinical settings for diagnostic purposes. This allowed researchers to observe the congruence between the assessment results and the specific requirements of each child’s individual modulations.

6 Results and Discussion

6.1 Preliminary Experiment

In the context of GAS framework, evaluative targets have been established, specifically: Robotic Interaction, Mediator Interaction, and Game Execution. Each target is graded on a scale ranging from -2 (significantly below expected) to +2 (significantly above expected), with 0 indicating expected performance (TURNER-STOKES, 2009; KRASNY-PACINI et al., 2013). Table 6 presents the previously defined targets.

Table 6 – GAS for Three Defined Targets

Desired Outcomes	Robotic Interaction	Mediator Interaction	Game Execution
Much Worse (-2)	No contact, apprehension/aversion towards the robot	Difficulty in following instructions, lack of engagement	Failure to complete the games
Worse (-1)	No contact, disinterest in the robot	Understanding, but hesitation in instructions	Completion of up to 2 games
Expected (0)	Displays interest, some contact with the robot	Comprehension and adherence to instructions with mediator assistance	Completion of at least 3 out of 4 games
Better (+1)	Demonstrates involvement, multiple interactions with the robot	Comprehension and voluntary adherence to mediator's instructions	Complete all 4 games in the session at least once
Much Better (+2)	Proficient involvement, sustained interactions with the robot	Comprehension and autonomous adherence to instructions	Completion of all games, repetition of at least one

The initial two primary targets, Robotic Interaction and Mediator Interaction, hold significance for children with ASD due to their challenges in establishing visual and physical contact, communication, and social interaction. The third target, Game Execution, evaluates adherence to game rules. All targets carry equal weight (1), and achievement is determined by the equation:

$$T = 50 + C_x \sum_{i=1}^{N} X_i \quad \text{where} \quad N = 3$$

where C_x represents the coefficient of the number of general targets (for three targets, it takes the value 4.56), and X_i is the sum of GAS scores obtained from the defined targets. A T value exceeding 50 reflects performance above expectations; $T = 50$ corresponds to expected performance; and a T value below 50 indicates performance below expectations (KRASNY-PACINI et al., 2013).

Since GAS scores above 50 indicate performance exceeding expected levels, the eleven children with ASD (from AMAES and APAE Vila Velha) exhibited exceptional performance. This is evident in the mean scores for each child presented in Tables 7 and 8, both at the outset and conclusion of the assessments. Consequently, the evaluated objectives yielded outcomes surpassing expectations, implying a remarkably positive Child-Robot Interaction (CRI).

Table 7 – Mean values of GAS scale by AMAES child*

Participants	Initial	Final
C1	59.12	77.36
C2	54.56	59.12
C3	54.56	77.36
C4	50.00	77.36
C5	54.56	77.36
C6	40.88	54.56
C7	54.56	77.36
Total Mean	52.60	71.49

* The data was analyzed using the paired t-test, with $p < 0.01$.

Table 8 – Mean values of GAS scale for the children of APAE Vila Velha*

Participants	Initial	Final
C8	50.00	68.24
C9	54.56	77.36
C10	54.56	77.36
C11	54.56	68.24
Total Mean	53.42	72.80

* The data was analyzed using the paired t-test, with $p < 0.01$.

The comparison of data for each child was conducted using the paired t-test, which evaluates the same individuals at different time points (HSU; LACHENBRUCH, 2014). Employing a significance level ($p - value$) below 0.05, the acquired $p - values$, below 0.01, indicate significant differences in the data. The final scores were notably higher than the initial scores.

When comparing pre- and post-interaction session data, an enhancement in interaction with the robot, mediator, and game performance was observed. Concerning Robot Interaction, in the initial session, the majority displayed up to two forms of simultaneous contact, including visual, physical, and verbal. Subsequent sessions reflected an increase in interaction levels. In the final session, all participants achieved all three types of contact, although some required encouragement.

For the second objective (Mediator Interaction), seven out of eleven children comprehended and executed commands with encouragement. C4, C8, and C11 needed mediator assistance, whereas C6 encountered challenges. By the conclusion, even children comprehended and executed commands spontaneously. C8 and C11 required encouragement, and C2 resisted. Child 6 depended on the mediator, with the robot MARIA T21 facilitating communication.

Regarding the third objective (Game Execution), ten children completed up to 2 out of 4 games, with C4 and C6 excelling in only 1. C1 performed well, completing 3 games. C2 and C6 demonstrated performance below expectations. C8 and C11 completed all games at least once. Seven children finished all games and repeated at least one, primarily Hungry Bird.

Based on the research conducted by Scassellati et al. (2012), the analysis of repeated interactions allows users to adapt over time, enabling the observation of the evolution of their behaviors towards the robot, resulting in improvements in children's performance, as observed in all cases. The results presented in Tables 7 and 8 reflect these advancements with respect to the established objectives. It is noteworthy that a previous study carried out by Goulart (2015), which assessed a single child-robot interaction session using the GAS scale, yielded results below the overall average achieved in the final evaluation of this study, underscoring the importance of continuous interaction with the robot to achieve more significant improvements. These conclusions highlight the potential of robots as therapeutic tools for children with ASD, stimulating their interest and contributing to cognitive and social development, also observed by Costa et al. (2015).

The SUS scale was completed by parents, caregivers, and therapists from both participating institutions after attending at least one session. The results are presented in Table 9, where the average scores obtained demonstrate consistent positive perceptions among therapists and parents regarding the well-integrated and user-friendly nature of the game-robot system.

The values presented in Table 9 consistently exceed 70 points across all situations, surpassing the average score of 68 points on the SUS scale, indicating superior performance

Table 9 – Average SUS Scale Values

Group	Average Score
AMAES Parents	76.07
APAE Parents	72.50
Professionals	78.33
Total Average	75.63

(BROOKE, 2013). These scores underscore the system's effectiveness as perceived by the participants.

Moreover, the results reveal a strong inclination among therapists and parents to view the game-robot system as a valuable tool for supporting therapy for children diagnosed with ASD. This aligns with the various developmental aspects addressed in such therapeutic interventions (ARSHAD et al., 2020).

Tables 10 and 11 present the outcomes, revealing improvements in selectivity and attention alternation aspects assessed by the TAC for most children. The post-intervention score drop for Child 3 can be partly attributed to his low engagement on the evaluation day, as reported by the mother, due to an ongoing medication change. A similar situation occurred with Child 4, who exhibited slightly increased restlessness in the study's final sessions due to medication adjustments.

Among AMAES participants (Table 10), C6 exhibited notable difficulties in games and tests, scoring lower due to attention and fine motor coordination challenges. In the post-intervention phase, C6 scored no points in part 2.

For APAE (Table 11), all children displayed gains in all three test parts, except C10, maintaining a consistent score in part 2. These positive findings underscore the validity of SGs and robot interactions in enhancing attention development for children with ASD.

Table 10 – Results of the AMAES TAC

Participants	Initial			Final		
	Part 1	Part 2	Part 3	Part 1	Part 2	Part 3
C1	25	2	31	31	3	37
C2	21	4	32	35	4	29
C3	23	2	23	14	2	18
C4	18	2	18	15	3	18
C5	14	2	19	23	5	17
C6	5	2	8	8	0	3
C7	16	2	17	16	2	25
Average	17.42	2.28	21.14	20.28	2.71	21

Table 11 – Results of the APAE Vila Velha TAC

Participants	Initial			Final		
	Part 1	Part 2	Part 3	Part 1	Part 2	Part 3
C8	5	0	6	10	1	10
C9	21	2	19	25	3	22
C10	14	1	12	22	1	17
C11	6	1	10	12	2	13
Average	11.5	1	11.75	17.25	1.75	15.5

Cognitive flexibility, evaluated using the TMT, involves the speed at which an individual's mental framework shifts in response to relevant cues from the environment (SCOTT, 1962). The test measures performance by accurately completing sequences in two parts (A and B), with part B specifically gauging cognitive flexibility.

Analyzing Table 12 data reveals that within the AMAES participants, during the second test round, six out of seven children successfully completed sequences. However, part A averages remained unchanged. Conversely, part B showed significant improvements, particularly with participants C1 and C3, who achieved maximum scores in this segment during the final assessment.

Regarding APAE children (Table 13), average scores changed for both parts A and B. All participants completed part A, and participants C9 and C10 attained maximum scores in part B. The psychologist responsible for their therapy noted a notable improvement in cognitive flexibility for individual C9. Once again, these results highlight the effectiveness of the studied system in promoting cognitive development among children with ASD.

Table 12 – Results of the AMAES TMT

Participants	Initial		Final	
	Part A	Part B	Part A	Part B
C1	4	1	4	9
C2	2	2	4	3
C3	4	0	4	9
C4	4	1	4	3
C5	4	1	4	4
C6	3	1	1	0
C7	4	2	4	3
Average	3.57	1.14	3.57	4.42

Table 13 – Results of the APAE Vila Velha TMT

Participants	Initial		Final	
	Part A	Part B	Part A	Part B
C8	1	1	4	1
C9	4	1	4	9
C10	4	1	4	9
C11	2	5	4	2
Average	2.75	2	4	5.25

Through the use of the Fonseca Psychomotor Battery, applied by physiotherapeutic professionals from the research team, it was possible to identify the psychomotor profiles of children with ASD before and after the interventions, as evidenced by the results presented in Tables 14 and 15.

The group of children that participated in 10 sessions demonstrated a progression in their psychomotor profile, transitioning from a dyspraxic state (2 points) to a eupraxic state (3 points), predominantly in the areas related to balance. Furthermore, a transition from the eupraxic state (3 points) to the hyperpraxic state (4 points) was observed in other psychomotor domains. In children subjected to 4 sessions, certain changes were observed, notably the shift from an apraxic profile (1 point) to a dyspraxic profile (2 points) in balance-related areas. Regarding the remaining psychomotor domains, changes were diverse or values remained unaltered (no significant changes occurred).

Table 14 – Psychomotor Profiles of Children from AMAES According to Fonseca's Psychomotor Battery

	Initial													Final												
	Subfactors*																									
	A	B	C	D	E	F	G	H	I	J	K	L	M	A	B	C	D	E	F	G	H	I	J	K	L	M
C1	3	3	3	2	3	2.92	3	3	3	3	3	2	4	4	4	4	3	3	3.5	4	4	3	3	4	2	4
C2	2	2	2	1	3	2.64	3	3	3	4	3	1	4	3	3	3	2	3	3.21	4	3	3	4	3	2	4
C3	3	2	3	2	3	2.64	4	4	3	3	3	2	4	3	3	3	2	3	3.21	4	4	4	4	4	3	4
C4	2	2	2	1	2	2.07	1	3	3	2	1	1	3	3	3	3	2	3	2.57	3	4	3	2	3	1	4
C5	2	2	2	1	2	2.07	2	3	3	3	3	2	4	3	3	3	2	3	2.57	3	4	3	3	3	3	4
C6	1	1	1	1	1	1.35	1	2	2	1	1	1	2	1	1	1	1	1	1.42	1	2	2	2	1	1	3
C7	3	2	2	1	3	2.42	4	4	3	2	3	2	4	4	3	3	2	3	3.28	4	4	3	3	4	2	4

*A) Immobility. B) Straight-line support. C) Tip-toes. D) Single-leg support. E) Controlled gait. F) Expressed as the mean for evolution subfactors in the dataset. G) Right-left recognition. H) Self-image. I) Gesture imitation. J) Body drawing. K) Dynamic structuring. L) Rhythmic structuring. M) Speed-precision.

Table 15 – Psychomotor Profiles of Children from APAE According to Fonseca's Psychomotor Battery

	Initial													Final												
	Subfactors*																									
	A	B	C	D	E	F	G	H	I	J	K	L	M	A	B	C	D	E	F	G	H	I	J	K	L	M
C8	1	1	1	1	1	1.28	1	2	2	2	2	1	3	1	2	2	1	2	1.85	1	2	2	2	3	1	4
C9	2	2	1	1	1	1.92	3	3	3	3	3	2	4	3	2	2	2	2	2.35	3	4	3	3	3	2	4
C10	3	3	3	2	3	3.21	4	3	3	3	3	3	4	3	4	4	2	3	3.35	4	4	4	3	4	3	3
C11	1	1	2	1	2	1.85	1	3	3	3	3	1	3	2	2	2	1	2	2	1	3	3	3	3	2	4

*A) Immobility. B) Straight-line support. C) Tip-toes. D) Single-leg support. E) Controlled gait. F) Expressed as the mean for evolution subfactors in the dataset. G) Right-left recognition. H) Self-image. I) Gesture imitation. J) Body drawing. K) Dynamic structuring. L) Rhythmic structuring. M) Speed-precision.

The most pronounced psychomotor deficit was identified in C6, who also exhibited cognitive deficits, particularly in relation to comprehending instructions during the assessment. However, even while maintaining consistency in the subfactor scores, there was a slight improvement in the ability to plan activities and execute movements of lesser amplitude, as well as in overall movement control. It is noteworthy that in the initial assessment, the child faced difficulties transitioning from a seated to a standing position (as reported by the mother regarding motor aspects). In the final assessment, however, the child managed to stand up with the assistance of hands.

In the case of C8, the initial results were lower compared to other participants, due to challenges in understanding instructions in both assessments. Nonetheless, by the end of the protocol, there was a subtle enhancement in movement control. As a trait present in some children with ASD, C2 exhibited remarkable sound sensitivity, which might have influenced the rhythmic structuring test.

Despite the positive outcomes, the preliminary experiment highlighted the necessity for more dynamic, specific, and flexible activities throughout the weeks of intervention. This is due to the observed decline in children's interest in engaging in repetitive and non-variable activities. Furthermore, all children were subjected to the same protocol, lacking specificity tailored to the individual characteristics and deficits within the autistic spectrum, as identified during the initial assessment.

6.2 Advanced Experiment

Based on the results obtained from the preliminary experiment, participants' assessment outcomes, and their availability and preferences, it was determined which games and dynamics each child participating would engage in during the advanced experiment. Table 16 provides an overview of the relationships between SGs and dynamics, including their duration and the participants involved.

In the Advanced Experiment, the established objectives for the GAS scale took into consideration evaluating participants performance in at least one game from each evaluation area, both with and without DDA. These games were: Memo, CrossKids, and Bricks Breaker (Table 17).

When examining the results, it is evident that in most cases, mean GAS scale scores are higher when participants are in the "With DDA" condition compared to the "Without DDA" condition. This indicates that the introduction of DDA had a positive impact on participants' performance and goal achievement in the games evaluated (Memo, Hungry Bird,

Table 16 – Definition of the application of Serious Games and dynamics according to previous evaluation of children

Serious Games/Dynamics	Duration	Participants
Memo	8 Weeks	K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14, K15, K16, K17, K18
Goblin Rush	6 Weeks	K1, K4, K9, K11, K13, K16, K17, K18
MARIA's Homework	4 Weeks	K1, K4, K9, K11, K13, K16, K17, K18
CrossKids	8 Weeks	K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14, K15, K16, K17, K18
Raining Food	4 Weeks	K1, K4, K9, K11, K13, K16, K17, K18
Bricks Breaker	4 Weeks	K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14, K15, K16, K17, K18
Tracing	8 Weeks	K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14, K15, K16, K17, K18
Super Hero	4 Weeks	K1, K4, K9, K11, K13, K16, K17, K18

and Bricks Breaker).

Furthermore, the paired t-test, with a significance level of $p < 0.01$, confirms that the difference in GAS scale scores between the two conditions is highly statistically significant. This means that the implementation of DDA led to consistent and notable improvements in participant performance, aligning with the objectives established in the Advanced Experience.

Overall, these results suggest that the use of DDA in the selected games effectively improved the achievement of general objectives and the performance of participants, emphasizing its potential as an adaptive and beneficial approach in educational and therapeutic contexts.

Table 18 presents the results of the TMT, which is a measure used to assess cognitive function, specifically visual attention, visual perception, visual scanning, processing speed, and cognitive flexibility abilities. Participants underwent two parts of the test: Part A and Part B, with the number of errors committed in each part also recorded.

Observing the results, it can be noted that the majority of participants performed relatively well in Part A of the test, with an average of 3.27 points to complete it and an

Table 17 – Mean values of GAS scale for children of APAE Vitoria*

Child	Without DDA	With DDA
K1	63.68	68.24
K2	68.24	72.80
K3	68.24	68.24
K4	45.44	59.12
K5	77.36	77.36
K6	63.68	72.80
K7	59.12	63.68
K8	54.56	59.12
K9	68.24	77.36
K10	63.68	72.80
K11	63.68	72.80
K12	72.80	77.36
K13	72.80	77.36
K14	54.56	63.68
K15	45.44	54.56
K16	68.24	72.80
K17	68.24	72.80
K18	50.00	59.12

* The data was analyzed using the paired t-test, with $p < 0.01$.

average of 0.38 errors. This suggests that they have good visual attention and processing speed skills. However, Part B of the test, which involves a greater demand for cognitive flexibility and visual scanning, showed varied results. Some participants demonstrated difficulty, with an average of 4.33 points to complete it and an average of 1.61 errors. This may indicate challenges in the ability to switch between different types of tasks and maintain visual attention during more complex tasks. These results can be useful in identifying areas requiring intervention and cognitive development in evaluated individuals.

Table 19 provides an overview of the results obtained from the TAC conducted with participants. Each participant's performance is evaluated based on the number of correct responses, a score, and a classification that reflects their attention abilities in these three domains.

Table 18 – Results of the APAE Vitoria TMT

Participants	A (Points)	Errors A	B(Points)	Errors B
K1	4	1	0	0
K2	4	0	3	5
K3	4	0	3	1
K4	0	0	0	0
K5	4	0	9	0
K6	4	0	2	2
K7	1	2	0	0
K8	4	0	9	0
K9	1	1	1	2
K10	4	1	1	3
K11	4	0	7	3
K12	4	0	5	2
K13	4	0	5	2
K14	4	0	7	2
K15	4	0	7	1
K16	4	0	8	3
K17	4	0	9	1
K18	1	2	2	2
Average	3.27	0.38	4.33	1.61

Table 19 – Results of the APAE Vitoria TAC

Participants	Part 1 - Selective Attention			Part 2 - Sustained Attention with Demand			Part 3 - Alternating Attention		
	Correct	Score	Classification	Correct	Score	Classification	Correct	Score	Classification
K1	10	77	Low	1	100	Medium	5	90	Medium
K2	18	86	Medium	2	115	High	7	93	Medium
K3	26	89	Medium	1	87	Medium	25	85	Medium
K4	3	68	Very Low	0	0	Very Low	4	71	Low
K5	11	71	Low	1	91	Medium	12	89	Medium
K6	6	62	Very Low	2	107	Medium	11	86	Medium
K7	5	71	Low	0	0	Very Low	5	73	Low
K8	11	78	Low	1	100	Medium	9	96	Medium
K9	5	71	Low	1	94	Medium	9	79	Low
K10	11	71	Low	1	91	Medium	14	96	Medium
K11	16	83	Low	1	100	Medium	22	114	Medium
K12	25	93	Medium	2	115	High	23	115	High
K13	18	82	Low	1	91	Medium	14	96	Medium
K14	8	66	Very Low	2	107	Medium	12	89	Medium
K15	10	77	Low	1	100	Medium	2	86	Medium
K16	28	97	Medium	1	100	Medium	27	121	High
K17	22	90	Medium	2	115	High	25	118	High
K18	3	63	Very Low	0	0	Very Low	4	32	Very Low

In the selective attention section (Part 1), participants demonstrated varying levels of performance, with some achieving high scores and classifications while others scored lower, indicating differences in their ability to focus on specific elements within a task.

Moving on to the sustained attention with demand section (Part 2), results show that participants had a wide range of scores and classifications. Some individuals performed well in this area, achieving high scores and classifications, while others struggled, resulting in lower scores and classifications. This section measures the ability to maintain attention over an extended period while managing additional cognitive demands.

Lastly, in the alternating attention section (Part 3), participants again displayed a range of performance levels. Some participants excelled, achieving high scores and classifications, while others struggled with tasks requiring them to shift their attention between different elements. This section assesses the ability to switch between tasks or stimuli effectively.

Table 20 provides a summary of the total results of the TAC. This table combines the scores and classifications from all three parts of the test to provide an overall assessment of each participant's attention abilities.

Table 20 – Total result of TAC APAE Vitoria

Participants	Total Correct	Total Score	Classification
K1	16	73	Low
K2	27	83	Low
K3	52	85	Medium
K4	7	63	Very Low
K5	24	71	Low
K6	19	65	Very Low
K7	10	65	Very Low
K8	21	78	Low
K9	15	69	Very Low
K10	26	74	Low
K11	39	95	Medium
K12	50	106	Medium
K13	33	83	Low
K14	22	69	Very Low
K15	13	70	Low
K16	56	112	Medium
K17	49	105	Medium
K18	7	47	Very Low

The total results demonstrate that participants vary in their overall attention performance, with some achieving higher total scores and classifications denoting better attention abilities, while others have lower total scores and classifications, indicating challenges in attention-related tasks. These findings provide a comprehensive view of participants' attentional profiles and have guided the development of targeted interventions and strategies to improve attentional capabilities.

To expand the information on the participants' profile, in addition to an initial interview carried out with the families of all children, some were selected to carry out the PEDCAT assessment. The Figure 29 presents the PEDCAT T Score values. These scores are normative and are intrinsically related to age, as they compare the performance of the child evaluated to the normative performance of other children of the same age with typical development.

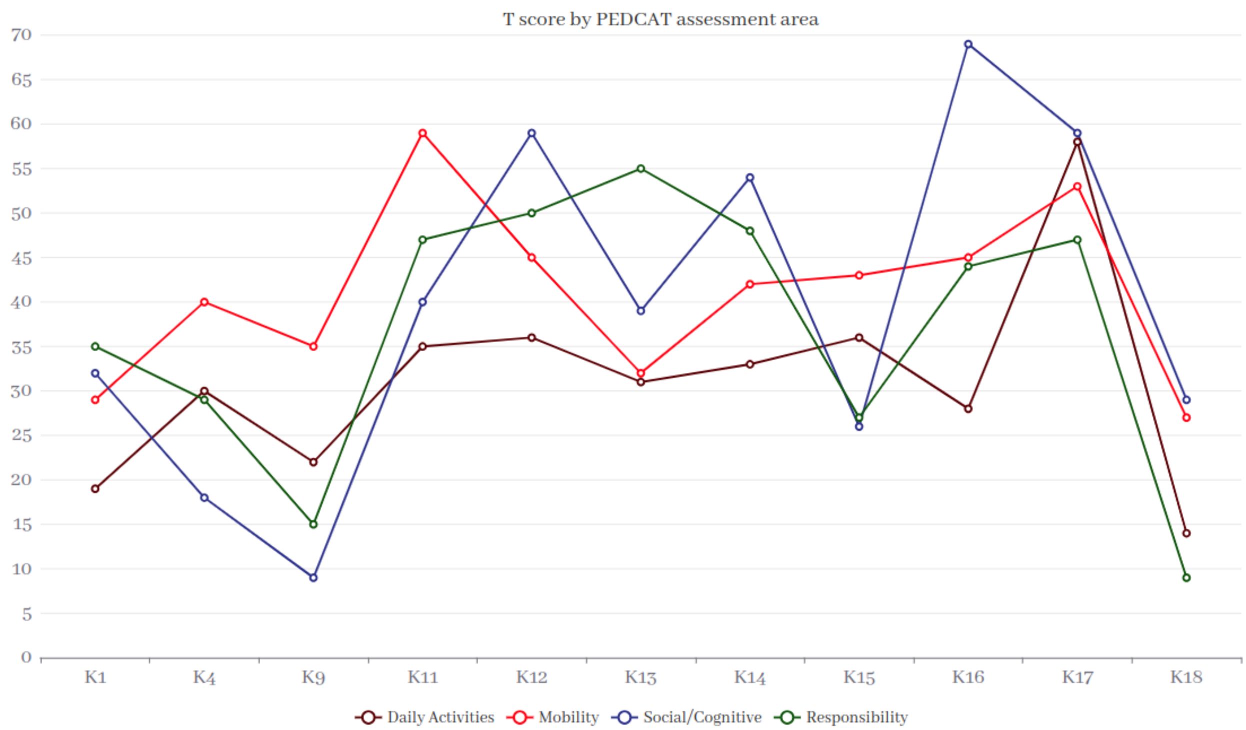


Figura 29 – PEDCAT T Score values

Analyzing the results, it is evident that participants demonstrate varying levels of functioning across the assessed domains. For example, in the "Daily Activities" domain, scores range from 14 to 36, indicating differences in the participants' ability to perform everyday tasks independently. Similarly, in the "Mobility" domain, scores vary from 27 to 59, reflecting disparities in participants' mobility and physical capabilities.

In the "Social/Cognitive" domain, participants display a wide range of scores, with some achieving relatively high scores (e.g., 69) and others scoring lower (e.g., <10). This suggests differences in social and cognitive skills, which are crucial for social interactions and cognitive development.

Lastly, in the "Responsibility" domain, scores range from <10 to 55, indicating differences in participants' sense of responsibility and their ability to take on tasks and obligations.

It is worth commenting that PEDCAT results provided a comprehensive view of participants' functional capabilities and limitations across multiple domains, to aid in intervention strategies and support plans tailored to each participant's specific needs, with the goal of improving their overall quality of life and functional independence.

6.2.1 Cognitive Module

The SG Memo was used by the 18 participants for 8 weeks, being 4 without DDA and 4 with DDA. The researchers provided guidance and support for the participants as needed (Figure 30), but always encouraged autonomy in decision-making and the use of the robot as the primary facilitator (Figure 31). The weekly time spent on this game was at least 15 minutes per child participant. Table 21 presents the number of games initiated by each child during the 15 minutes allocated for this SG exercise. Table 22 shows the number of weekly messages sent by the robot to each child during the 4 weeks when DDA was present, with the intention of maintaining and/or regaining the child's attention during the display of the color sequence.

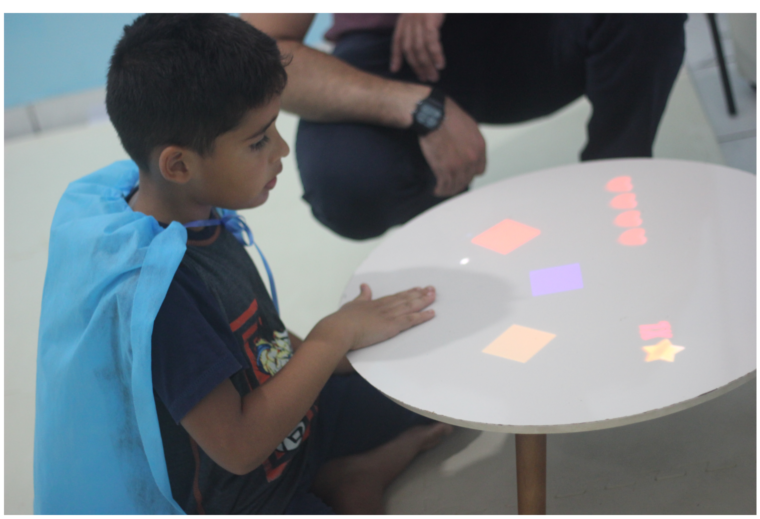


Figura 30 – Child receiving guidance on how to play Memo

Figura 31 – Children playing Memo

Table 21 – Number of games started within 15 minutes

Without DDA																		
Week/Participant	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18
1	8	7	6	8	6	7	6	9	10	8	7	7	7	6	9	4	4	9
2	6	7	6	4	6	7	6	9	8	8	4	8	7	7	8	5	4	8
3	8	6	5	9	6	8	5	8	9	7	6	6	7	7	9	4	5	5
4	7	6	5	7	6	7	5	9	9	8	4	4	6	6	11	4	6	8
With DDA																		
Week/Participant	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18
5	7	6	5	7	6	7	5	8	8	6	6	6	5	6	7	3	5	7
6	7	5	5	7	5	6	5	9	8	7	6	6	5	6	6	3	6	7
7	7	6	4	8	5	6	5	8	8	7	5	7	5	6	9	2	3	7
8	7	6	4	2	5	6	5	7	8	7	6	6	5	5	8	2	5	5

Table 22 – Number of attention calls

With Modulation																		
Week/Participant	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18
5	4	4	3	8	3	5	4	12	7	5	8	5	3	2	15	4	4	11
6	6	4	3	9	1	6	3	10	7	5	7	5	3	2	12	3	5	9
7	5	5	3	7	2	5	4	11	5	5	7	9	4	1	8	1	5	9
8	4	4	2	6	2	5	4	10	6	5	9	8	3	2	10	1	3	8

The t-test yielded $p < 0.01$ and indicated a significant correlation between the messages sent to maintain the child's focus and the increase in their achieved points. The test also indicated a correlation ($p < 0.01$) between the reduction in the number of games played in 15 minutes and the quantity of hints provided by the robot. The reduction in the number of games initiated reflects the longer duration that the player remained in advancing through the levels and earning points before finishing the game due to consecutive errors. Figures 32 to 49 present the individual performance of the 18 participating children, considering the highest score achieved each week (line) and the corresponding duration of the game (bars).

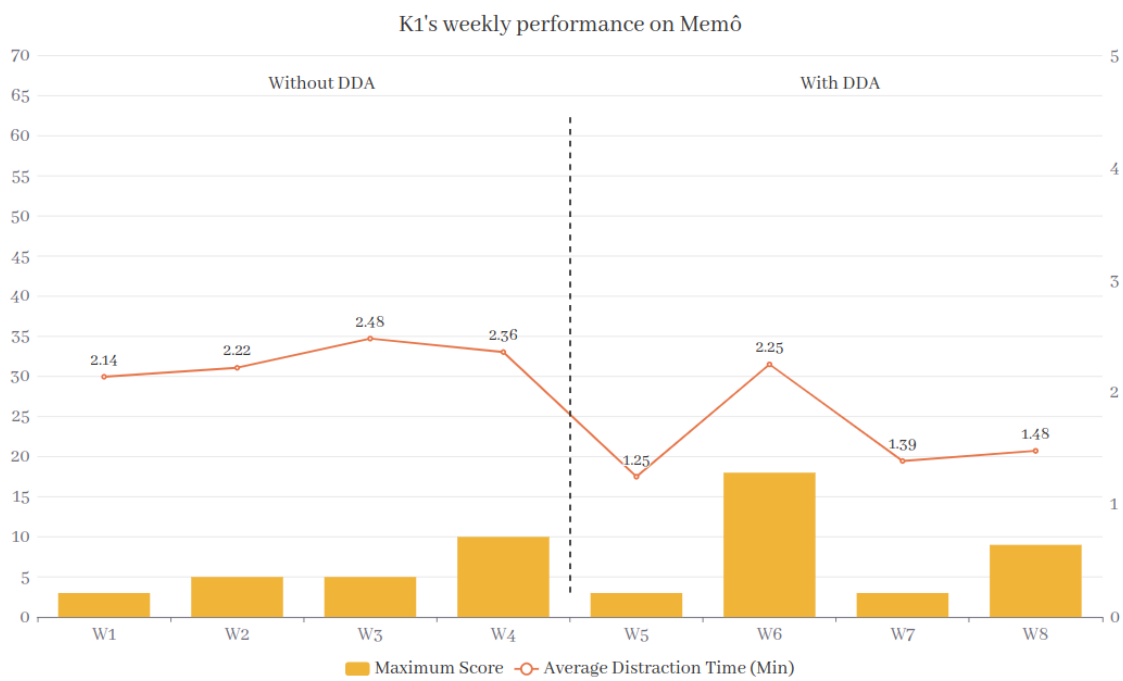


Figura 32 – Performance of participant K1 in the Memo

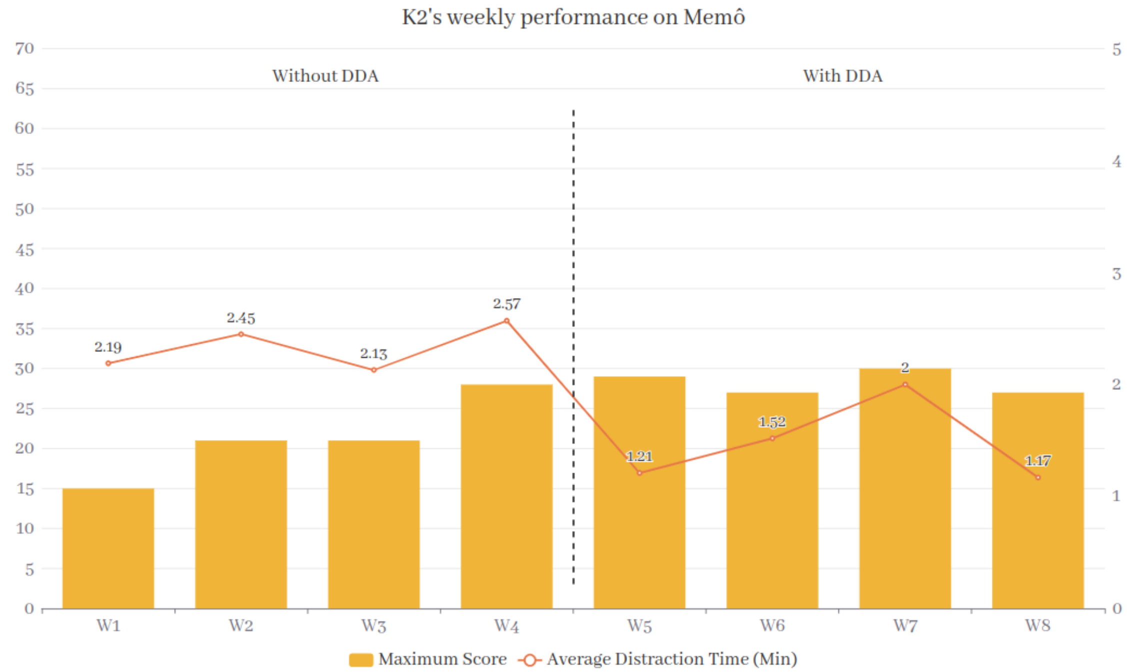


Figura 33 – Performance of participant K2 in the Memo

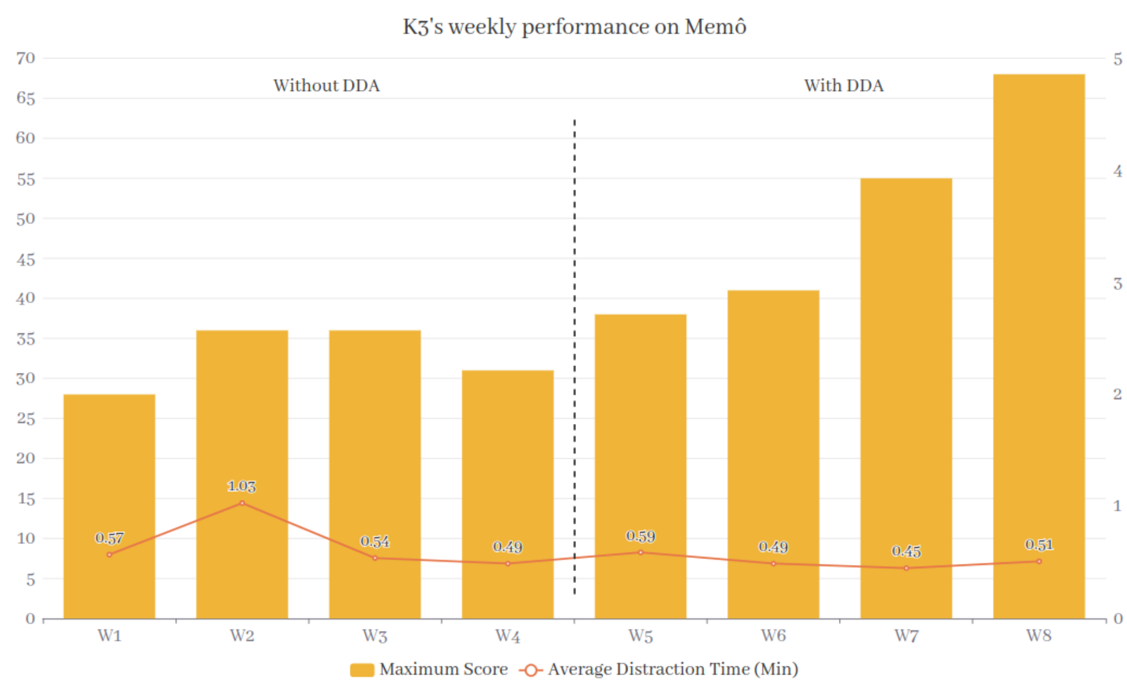


Figura 34 – Performance of participant K3 in the Memo

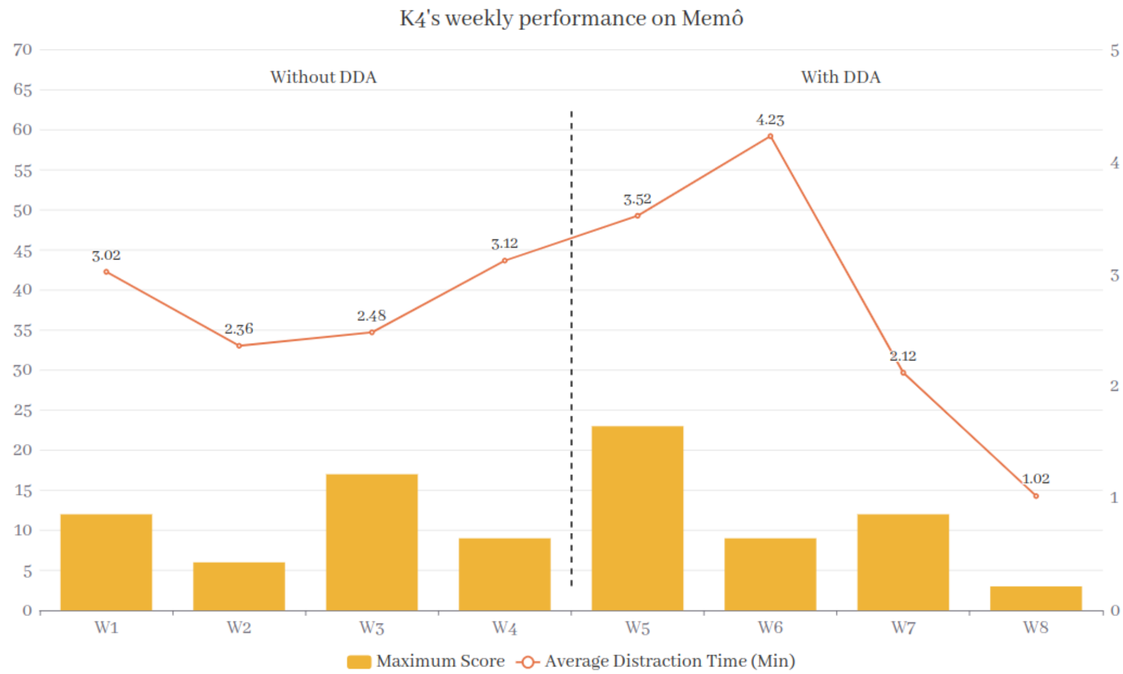


Figura 35 – Performance of participant K4 in the Memo

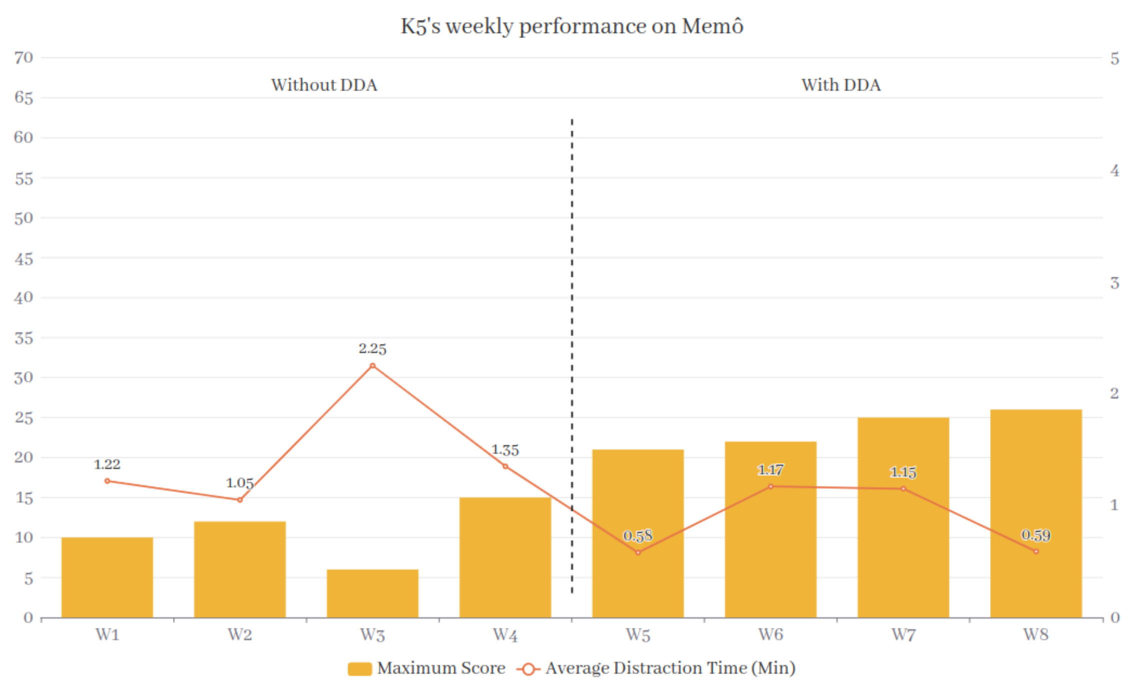


Figura 36 – Performance of participant K5 in the Memo

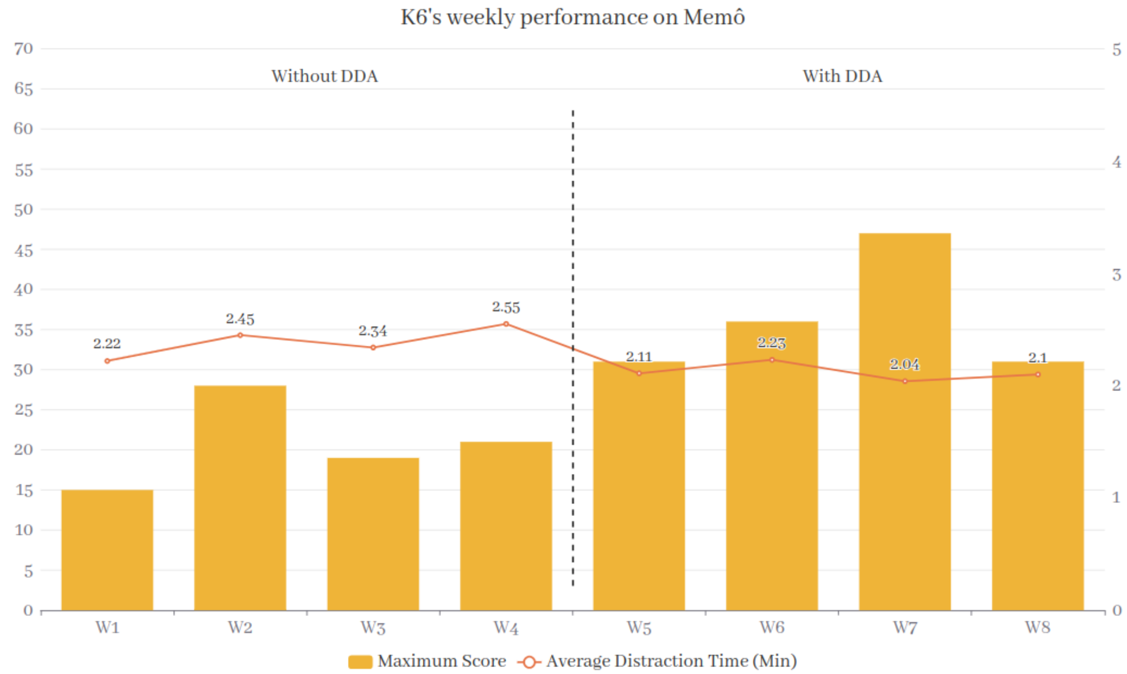


Figura 37 – Performance of participant K6 in the Memo

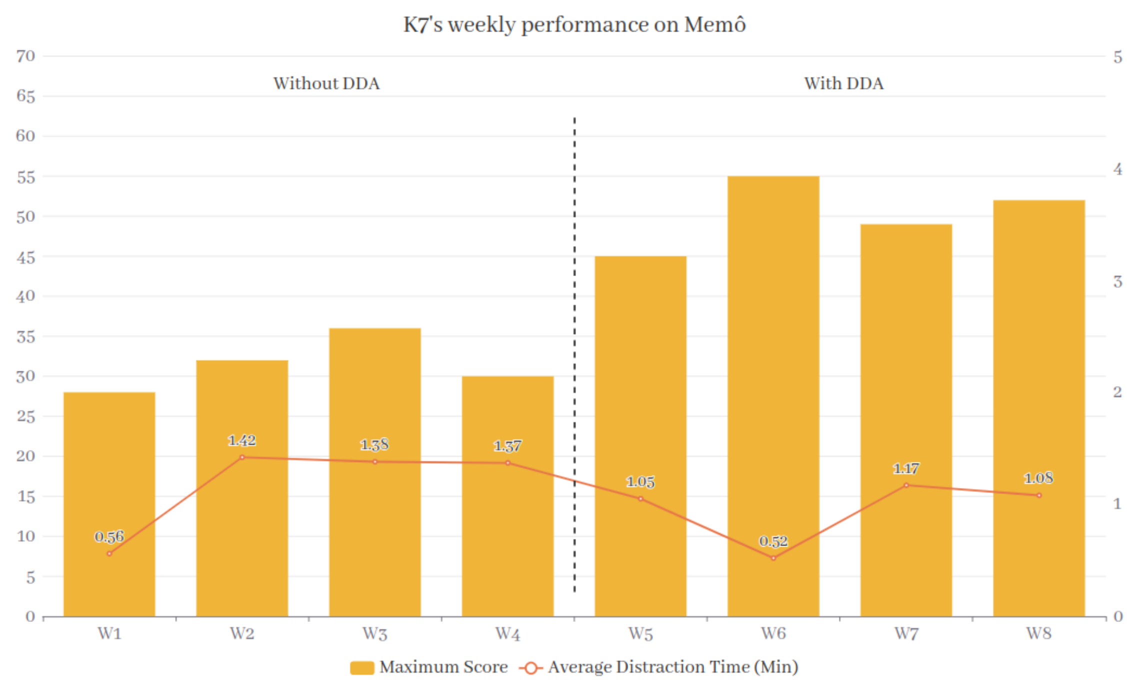


Figura 38 – Performance of participant K7 in the Memo

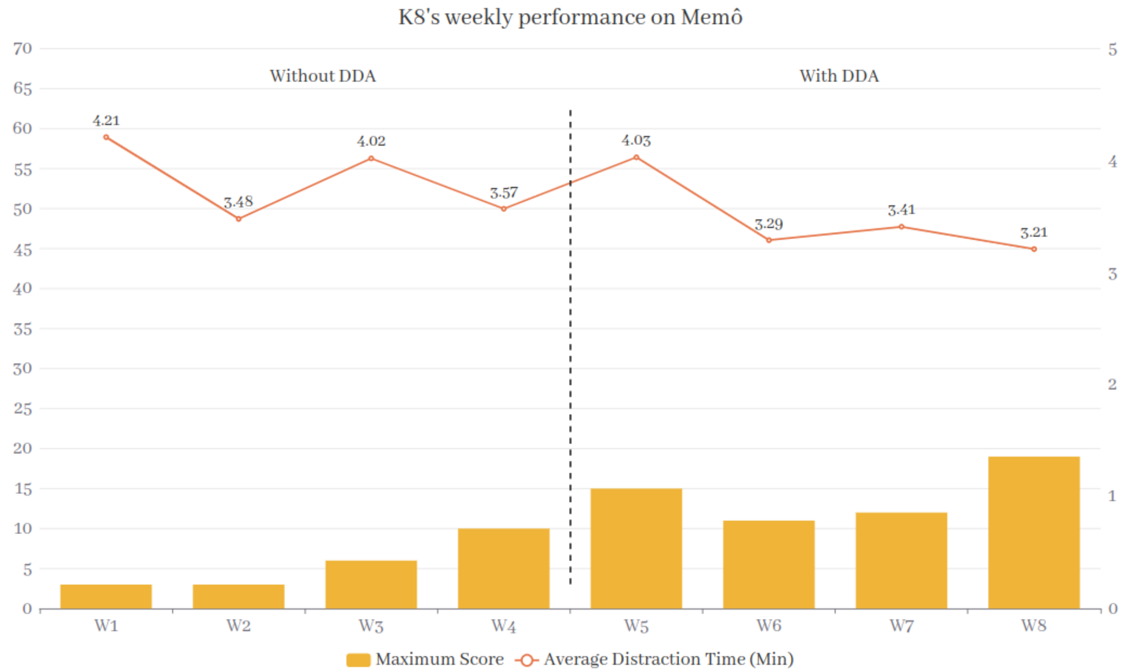


Figura 39 – Performance of participant K8 in the Memo

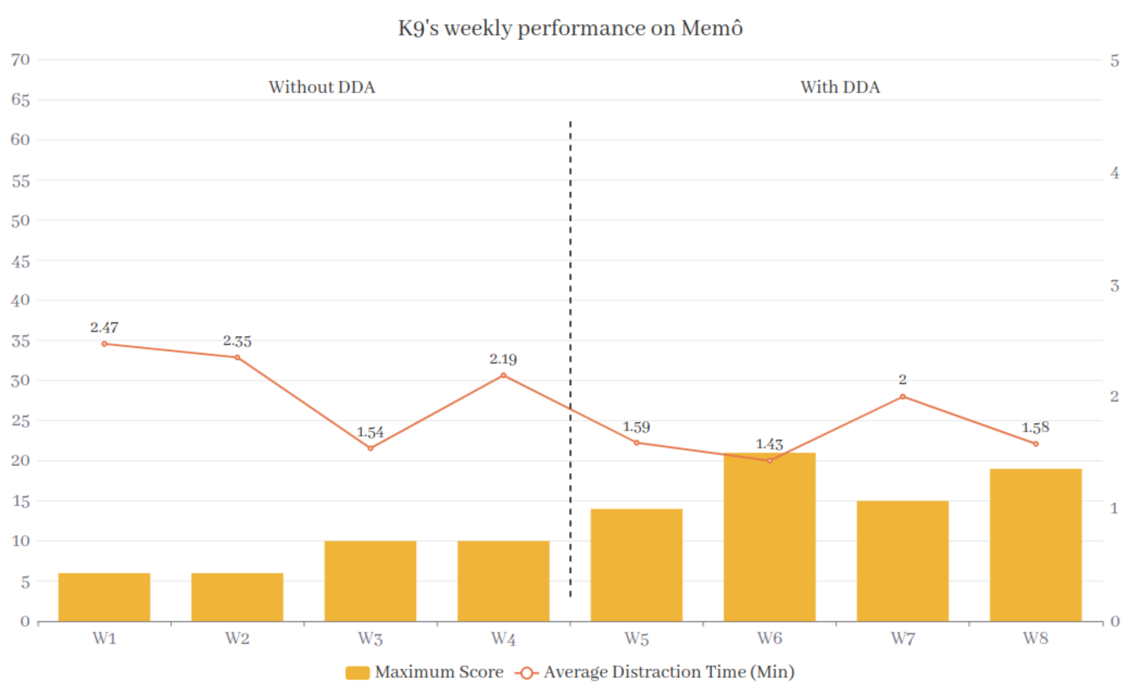


Figura 40 – Performance of participant K9 in the Memo

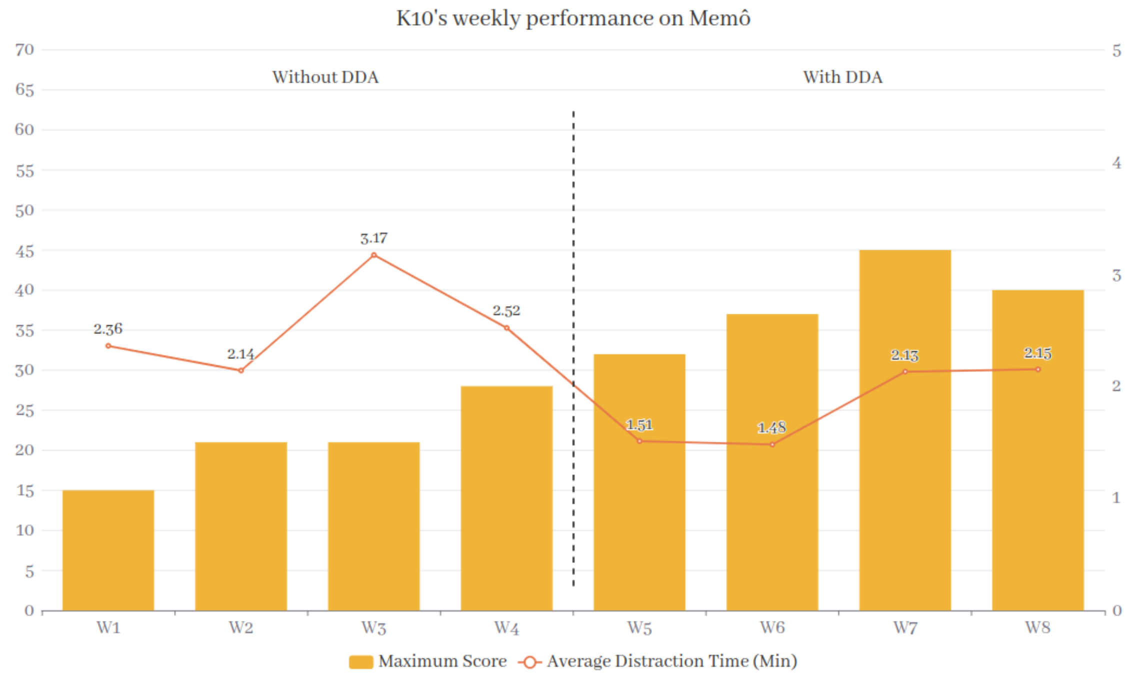


Figura 41 – Performance of participant K10 in the Memo

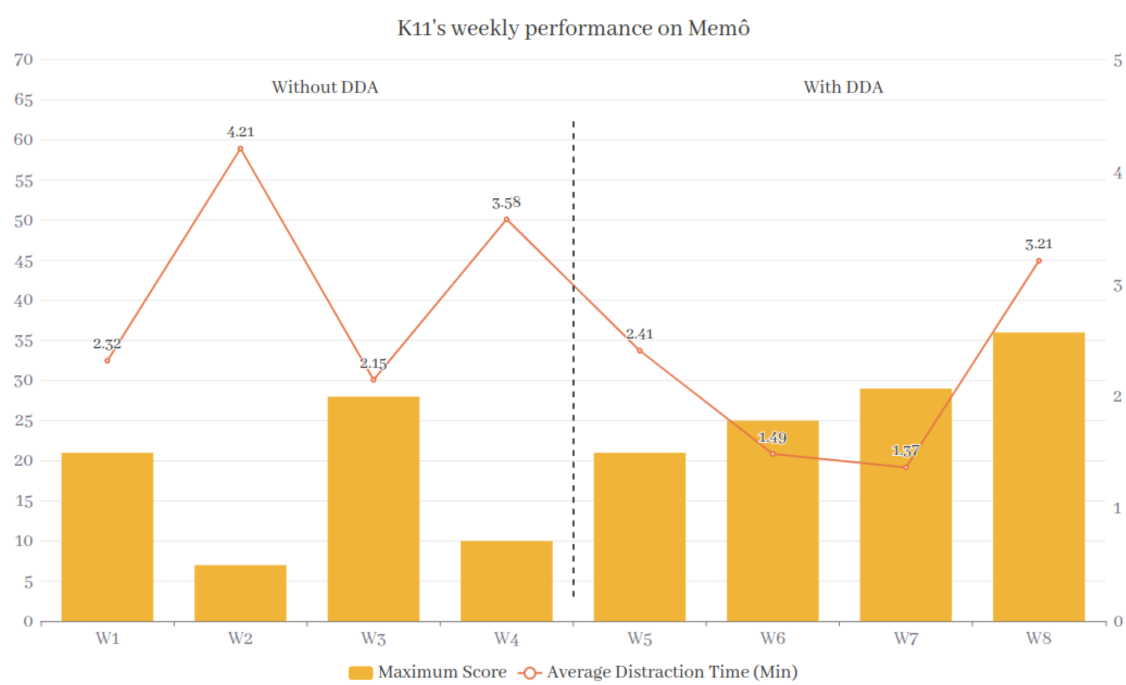


Figura 42 – Performance of participant K11 in the Memo

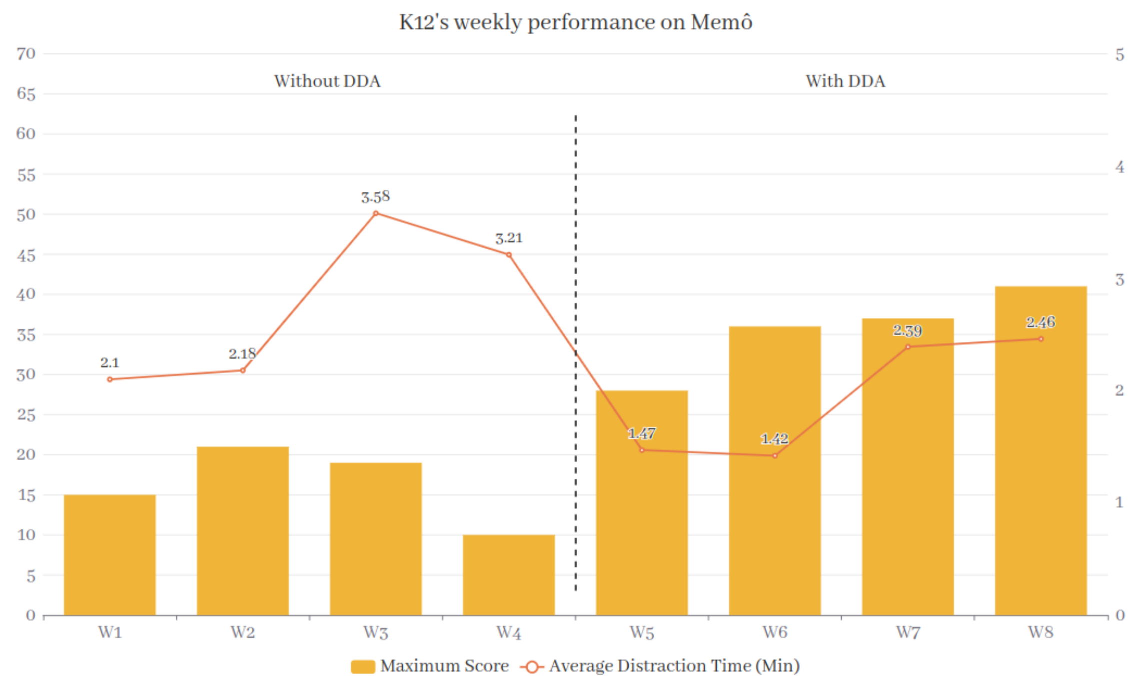


Figura 43 – Performance of participant K12 in the Memo

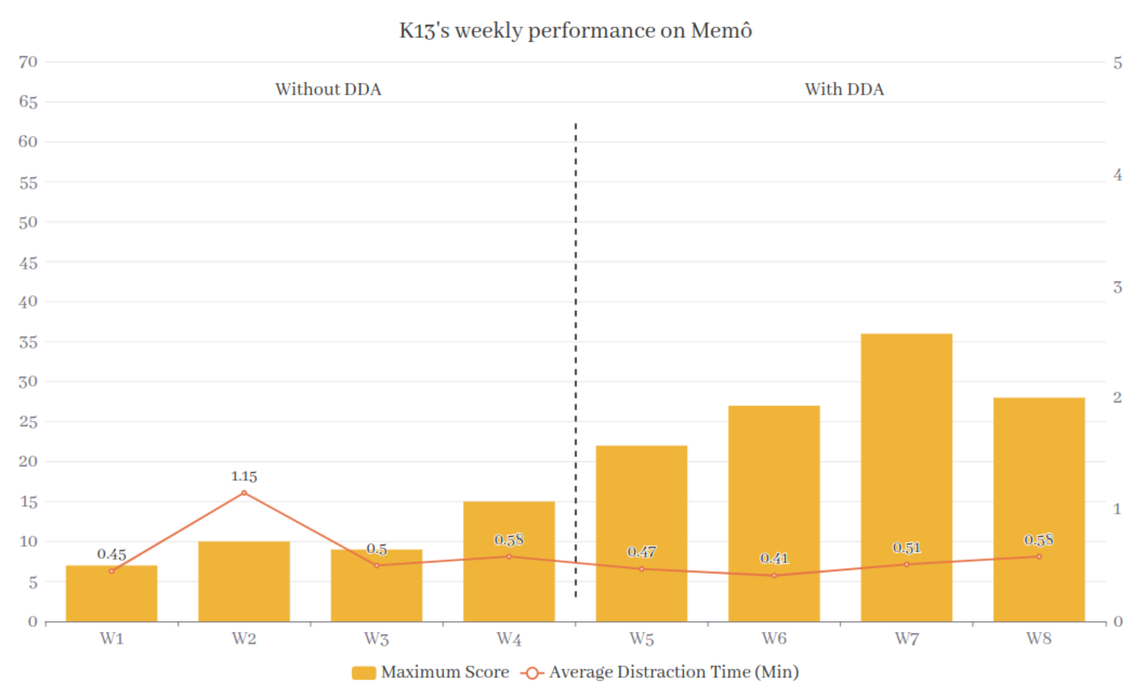


Figura 44 – Performance of participant K13 in the Memo

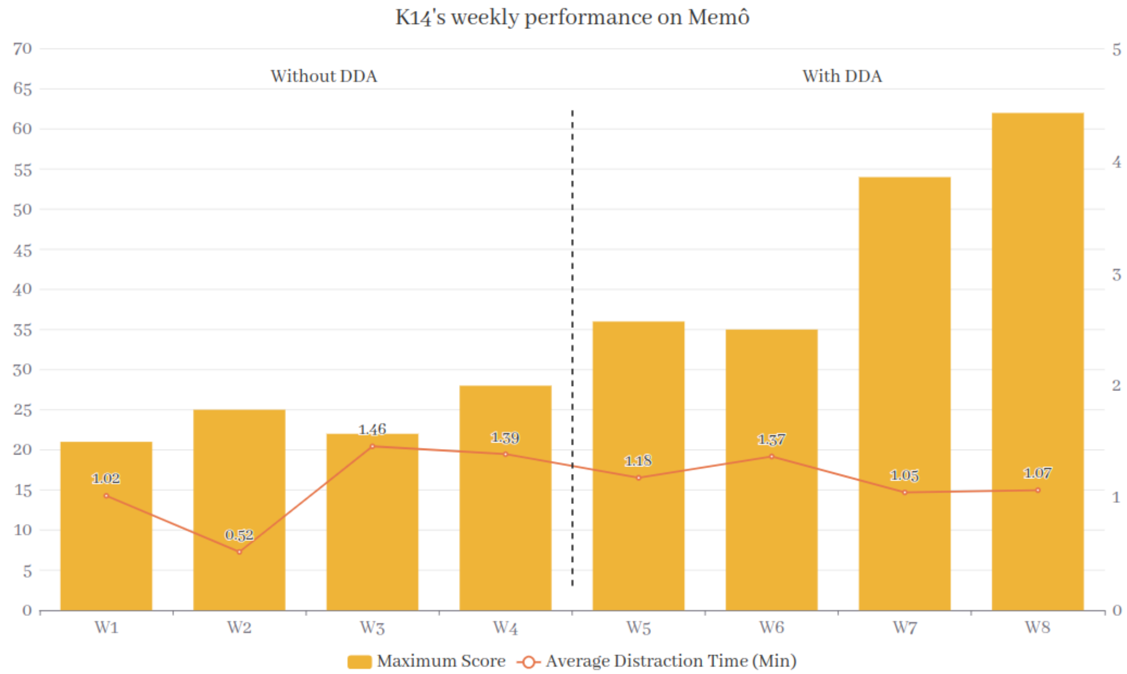


Figura 45 – Performance of participant K14 in the Memo

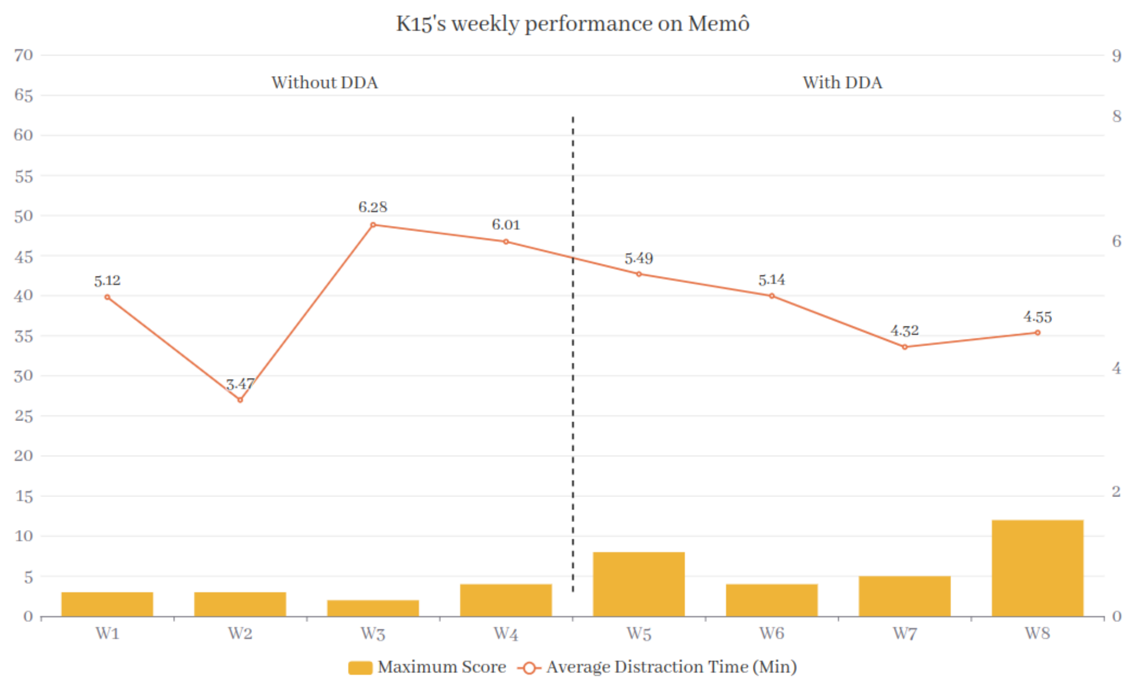


Figura 46 – Performance of participant K15 in the Memo

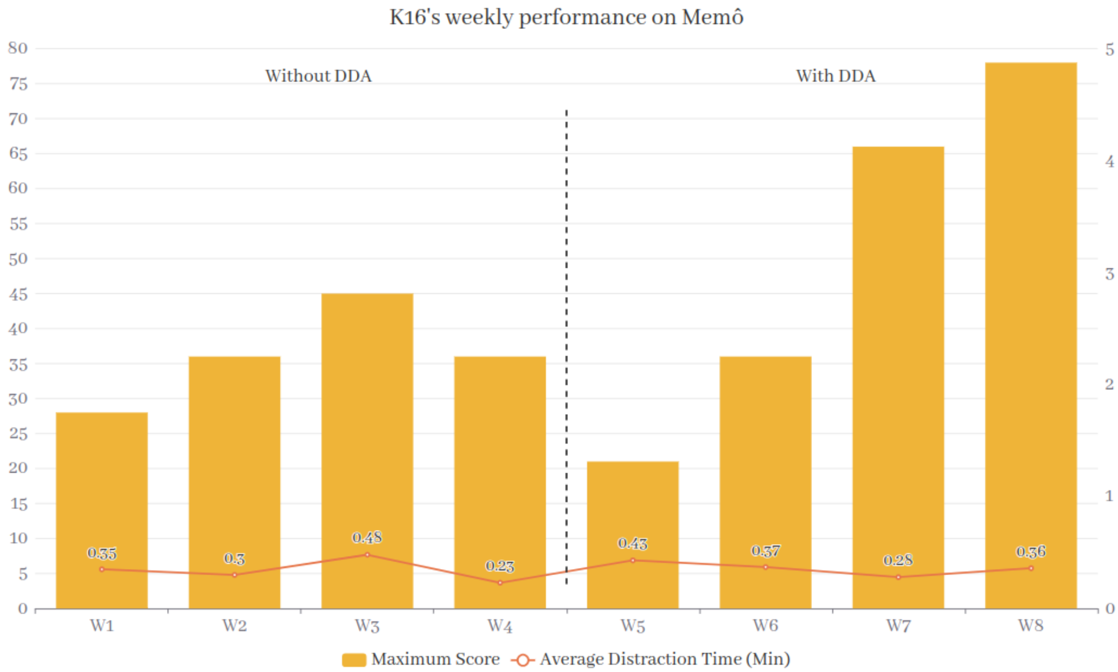


Figura 47 – Performance of participant K16 in the Memo

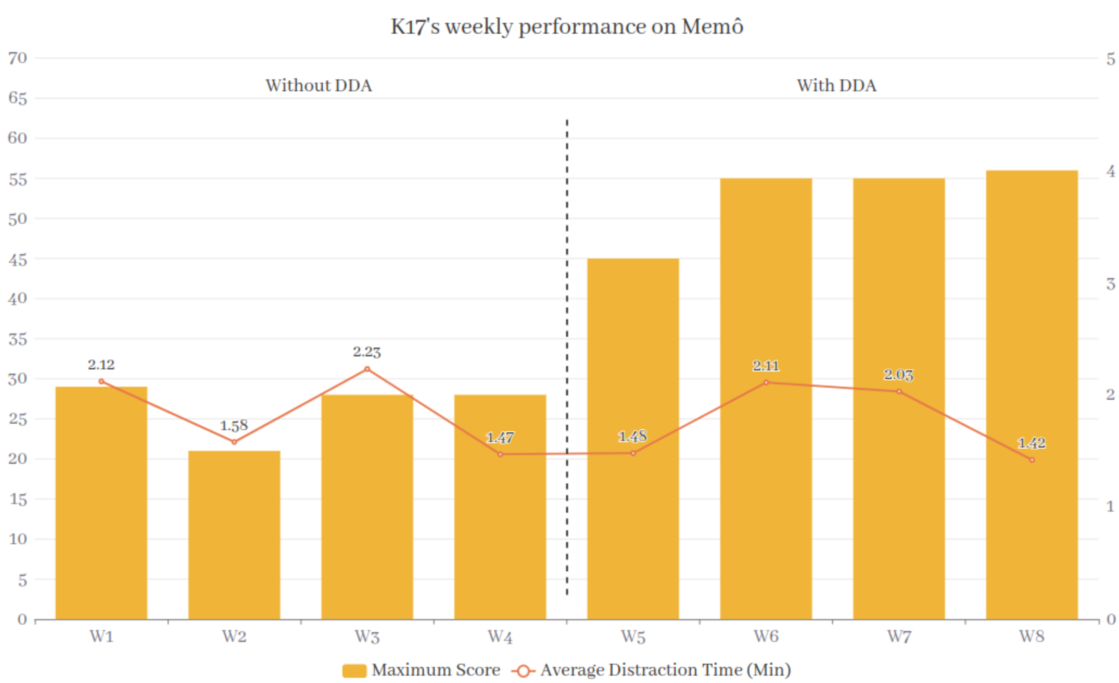


Figura 48 – Performance of participant K17 in the Memo

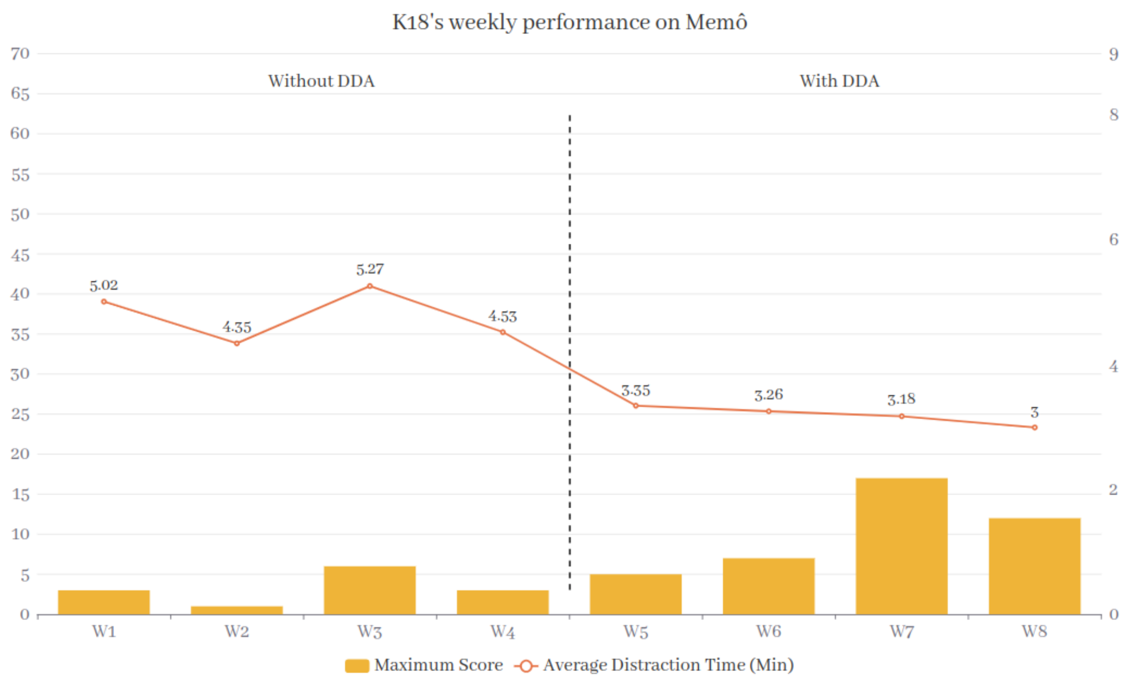


Figura 49 – Performance of participant K18 in the Memo

The MARIA's Homework SG was applied over a period of 4 weeks to 8 (K1, K4, K9, K11, K13, K16, K17, K18) of the participants. Activities of MARIA's Homework were selected based on affinities and deficits observed in the initial anamnesis and the results obtained in tests conducted previously. Figure 50 illustrates the first interaction of one of the participants with the activity, during which researchers' guidance, in addition to the robot's instructions, were required. Figure 51 shows some participants solving the questions autonomously or with partial assistance.

Figura 50 – Child receiving guidance on how to play MARIA's Homework

Figura 51 – Children playing MARIA's HomeWork

Results of the 8 children, described by the number of correct answers and the level of difficulty of the questions in the areas of Security and Self-Care (Figure 52), Mathematics (Figure 53), World Knowledge (Figure 54), Logic and Logical Reasoning (Figure 55), Knowledge of Shapes and Figures (Figure 56), and Recognition of Emotions and Feelings (Figure 57), are presented below.

Figura 52 – Weekly Outcome of Security and Self-Care in SG MARIA's Homework

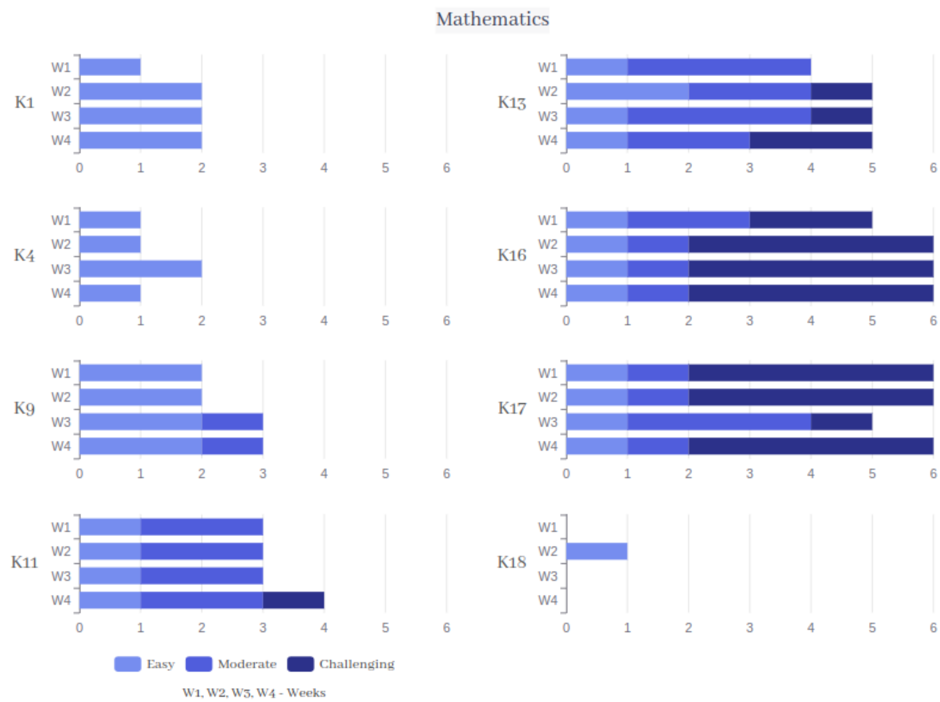


Figura 53 – Weekly Outcome of Mathematics in SG MARIA's Homework

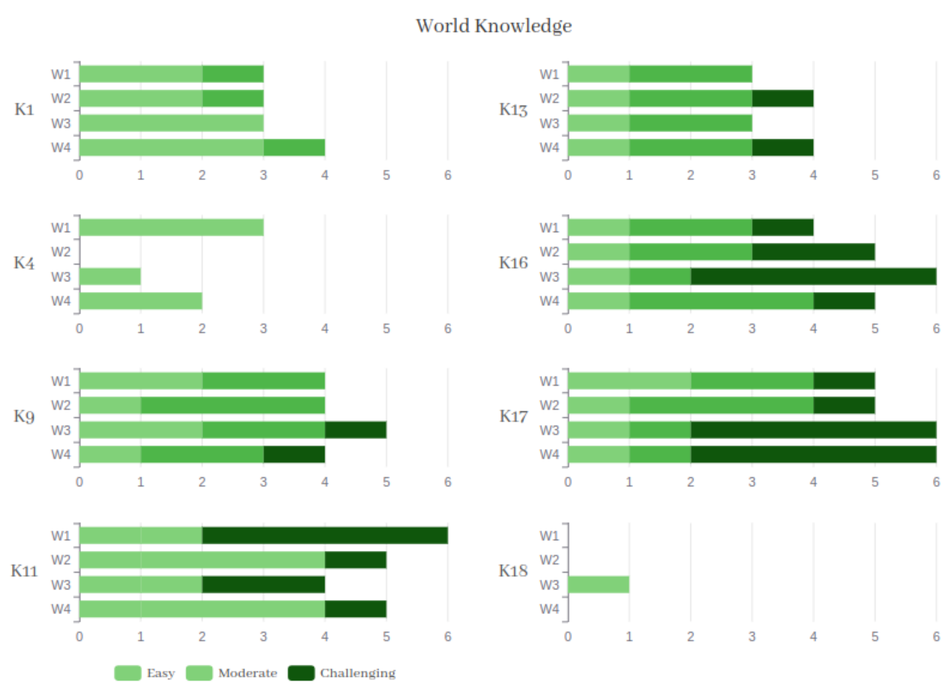


Figura 54 – Weekly Outcome of World Knowledge in SG MARIA's Homework

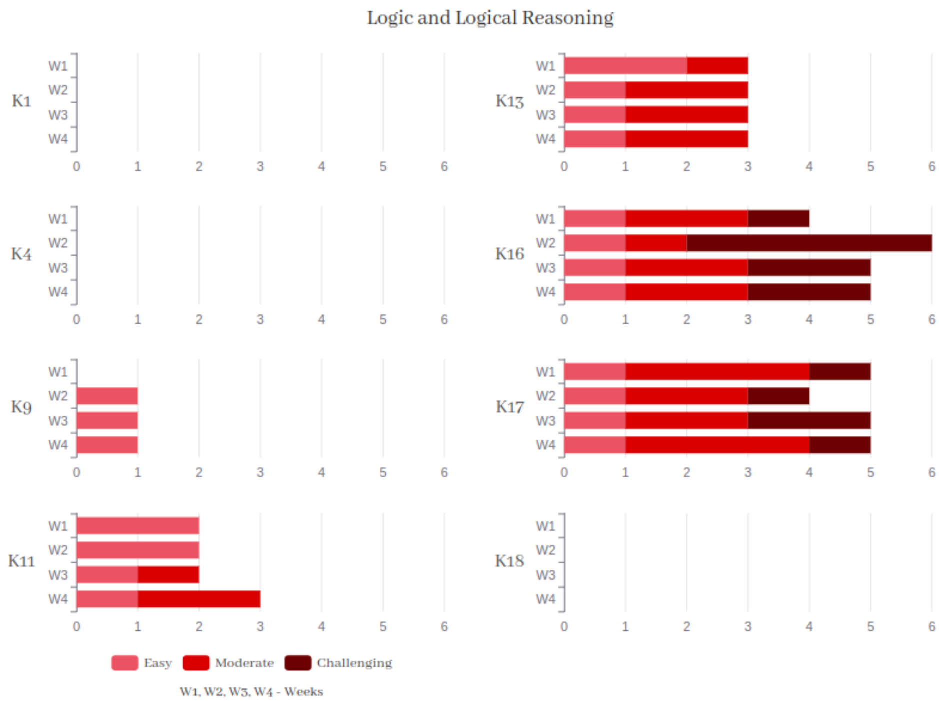


Figura 55 – Weekly Outcome of Logic and Logical Reasoning in SG MARIA's Homework

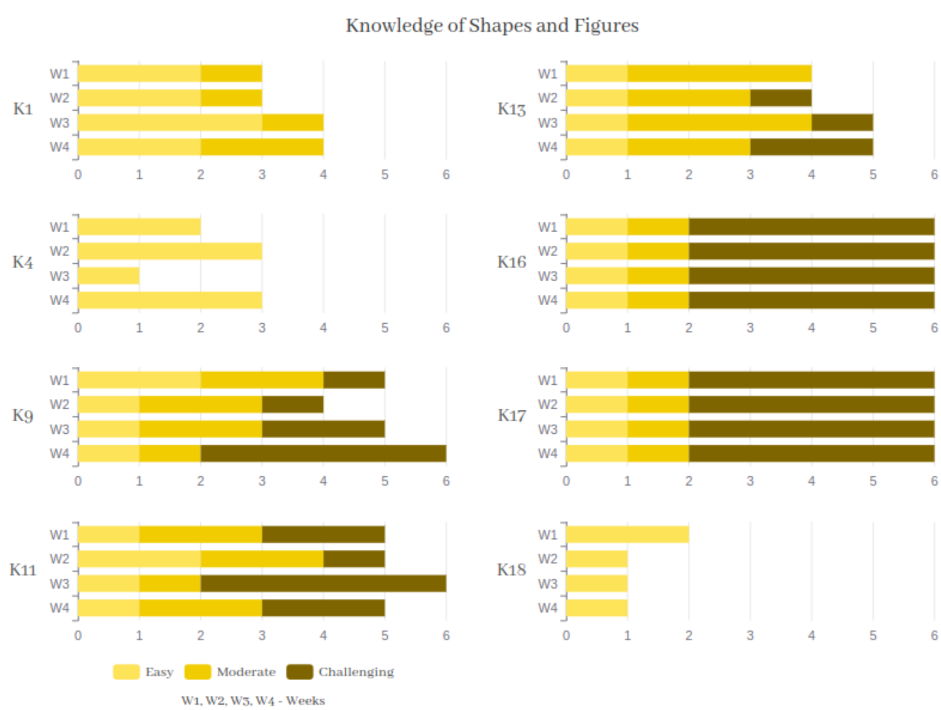


Figura 56 – Weekly Outcome of Knowledge of Shapes and Figures in SG MARIA's Homework

Figura 57 – Weekly Outcome of Recognition of Emotions and Feelings in SG MARIA's Homework

The Goblin Gold SG was primarily administered to children (K1, K4, K9,K11, K13, K16, K17, K18) with reports of attention and concentration problems related to ocular focus, and lasted for 6 weeks. During the execution of the SG, the controller observed the focal direction of the participant and manually adjusted the recognition distance based on the child's performance (Figure 58). Figure 59 depicts some of the participants engaged in playing Goblin Gold.

Figura 58 – Controller's view while the child plays Goblin Gold

Figura 59 – Children playing Goblin Gold

The individual performance of the participants in the first and last data collections for this SG is presented in Figures 60 to 65. The values in the vertical columns represent the performance per level and can be observed as percentages on the left side of the graphs. They correspond to the total lives the player had when completing the level, where 100 represents passing the level without losing any lives, and 0 indicates failure in the level.

The red “Life” and green “Speed” lines represent the values taken on by the life and speed multipliers of the enemies in the game, respectively, in order to reduce or increase the difficulty faced by the participants in defeating them.

The locations of the first 20 hits for each of the participants in the first and last weeks are also represented relative to the coordinates zero point, which corresponds to the location to be protected (the treasure chest). Different types of enemies are represented by the radius size of the circles, and the recognition distance is specified.

Figura 60 – K1's performance in SG Goblin Gold

Figura 61 – K9's performance in SG Goblin Gold

Figura 62 – K11's performance in SG Goblin Gold

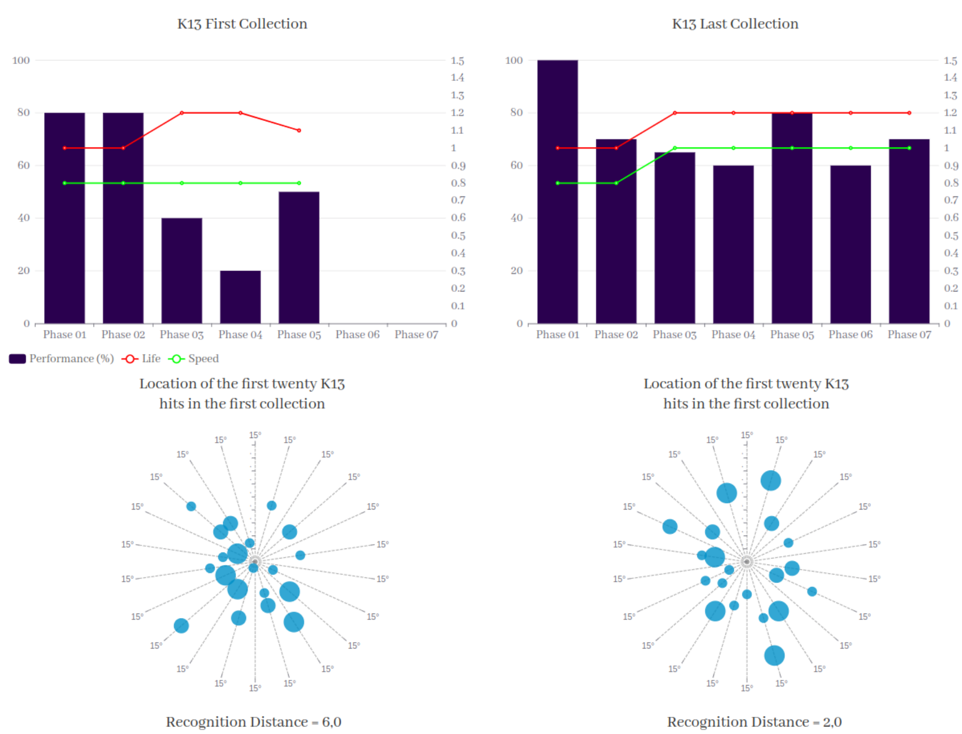


Figura 63 – K13's performance in SG Goblin Gold

Figura 64 – K16's performance in SG Goblin Gold

Figura 65 – K17's performance in SG Goblin Gold

6.2.2 Physical Module

The CrossKids SG was used with all 18 participants (K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14, K15, K16, K17, K18) over a period of 8 weeks. Figure 66 shows the way to be followed by children in the balance phase in this SG. Figures 67 to 84 show the path actually followed by the child in the first and in the last of 8 sessions. The path was obtained using the lidar sensor embedded in the SAR MARIA T21 and entrepreneur to control the SG.

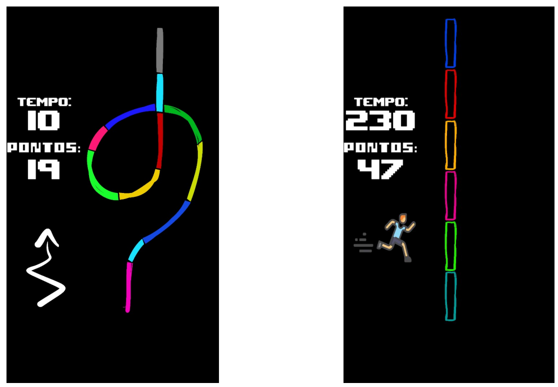


Figura 66 – Crosskids balancing phases

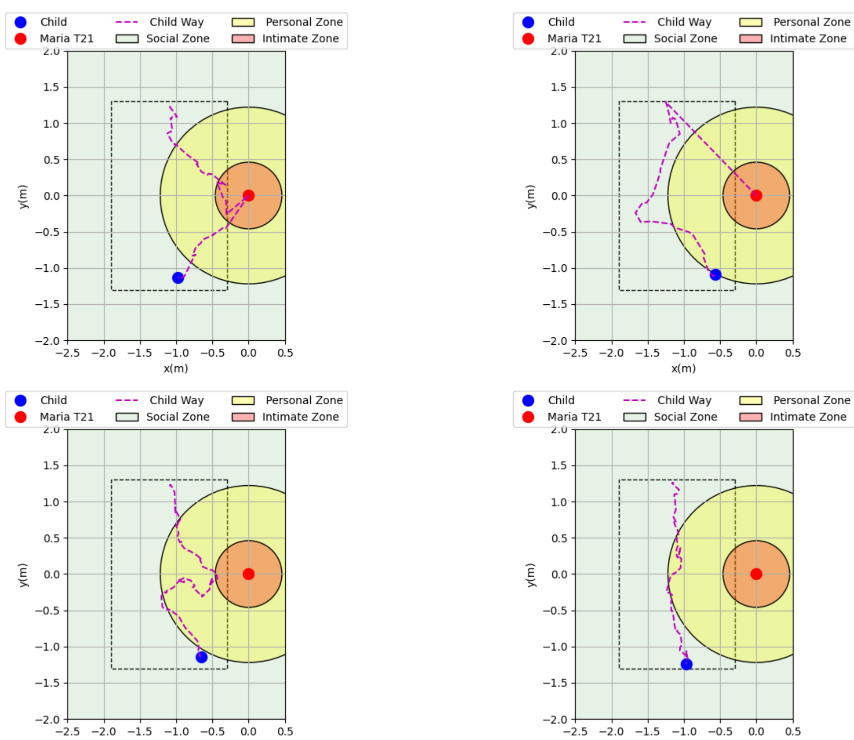


Figura 67 – K1 performance in the first and last week

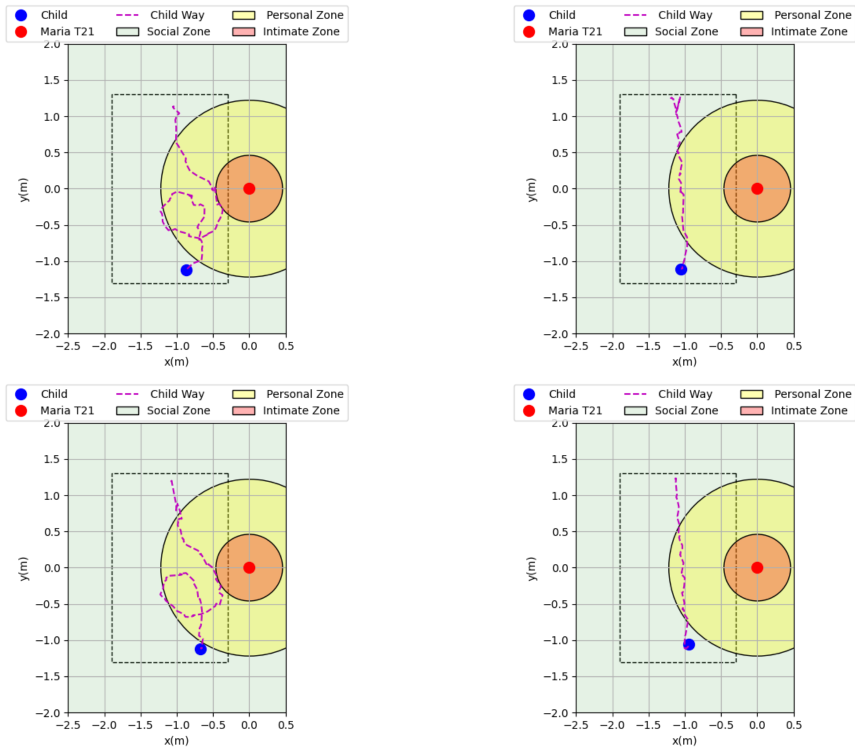


Figura 68 – K2 performance in the first and last week

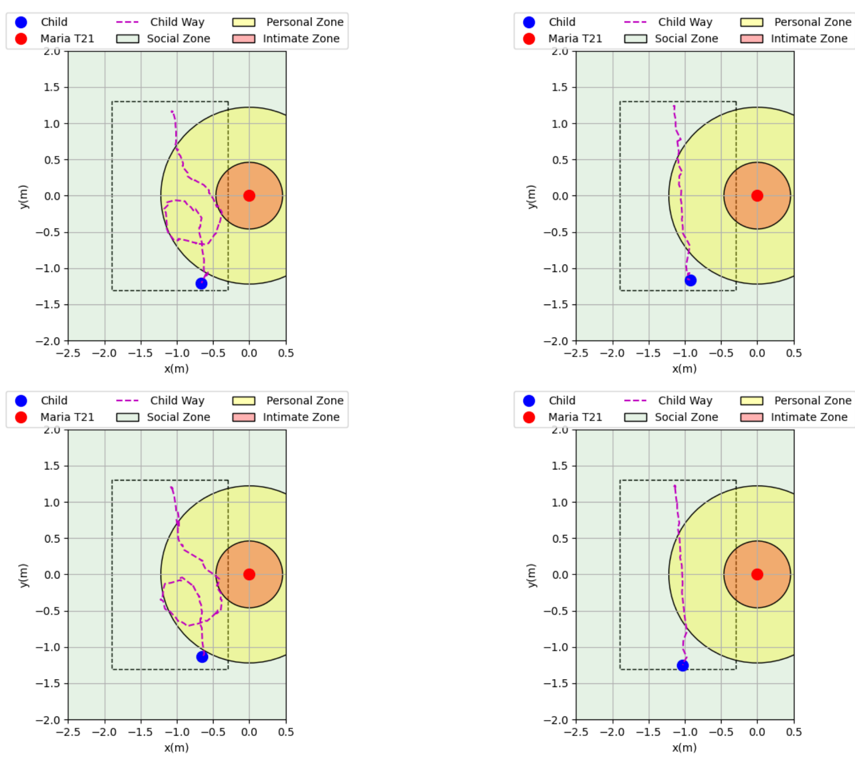


Figura 69 – K3 performance in the first and last week

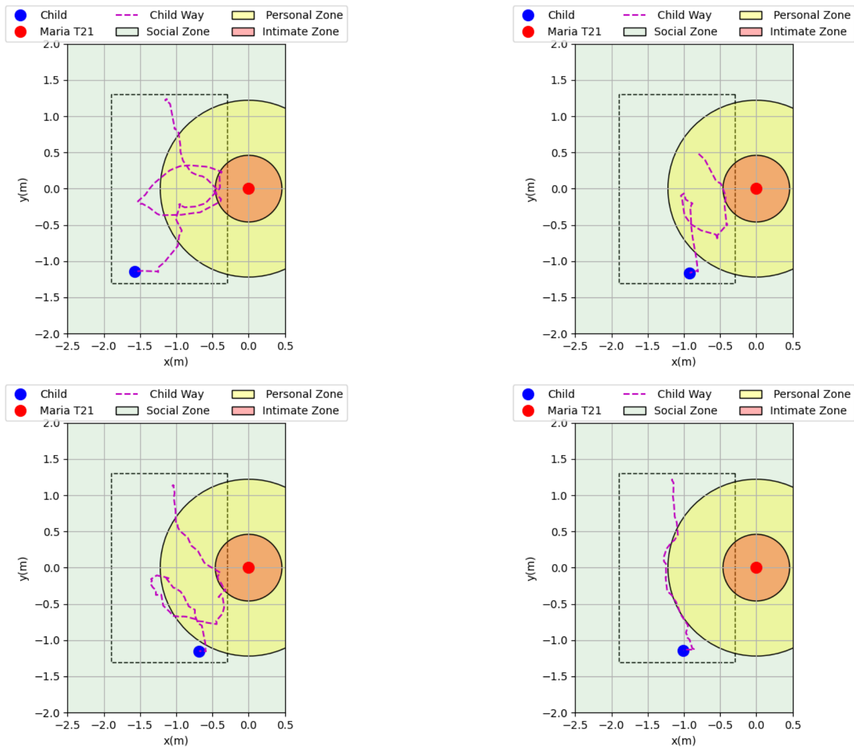


Figura 70 – K4 performance in the first and last week

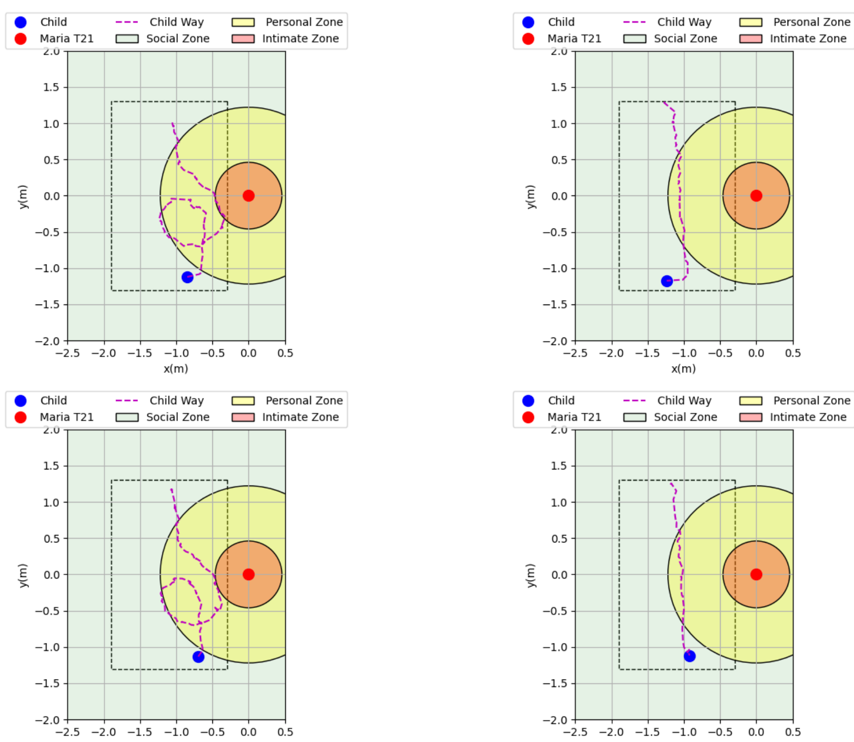


Figura 71 – K5 performance in the first and last week

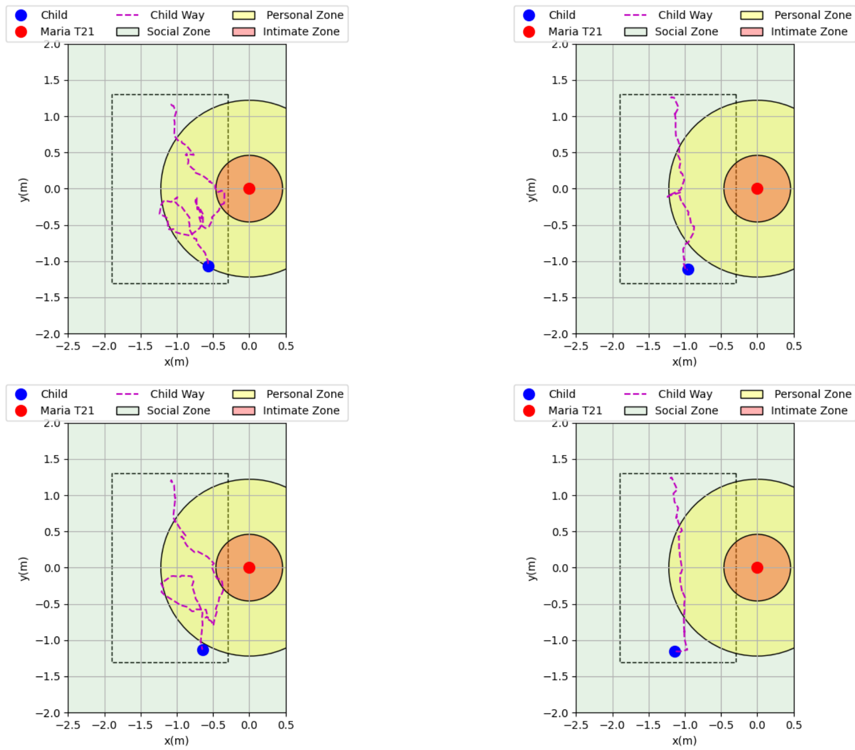


Figura 72 – K6 performance in the first and last week

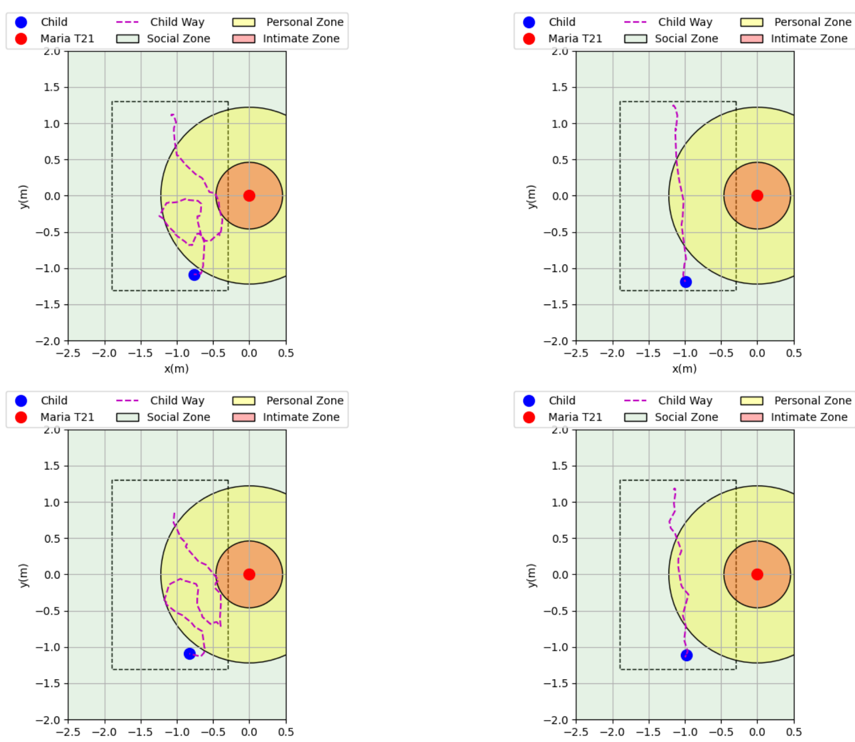


Figura 73 – K7 performance in the first and last week

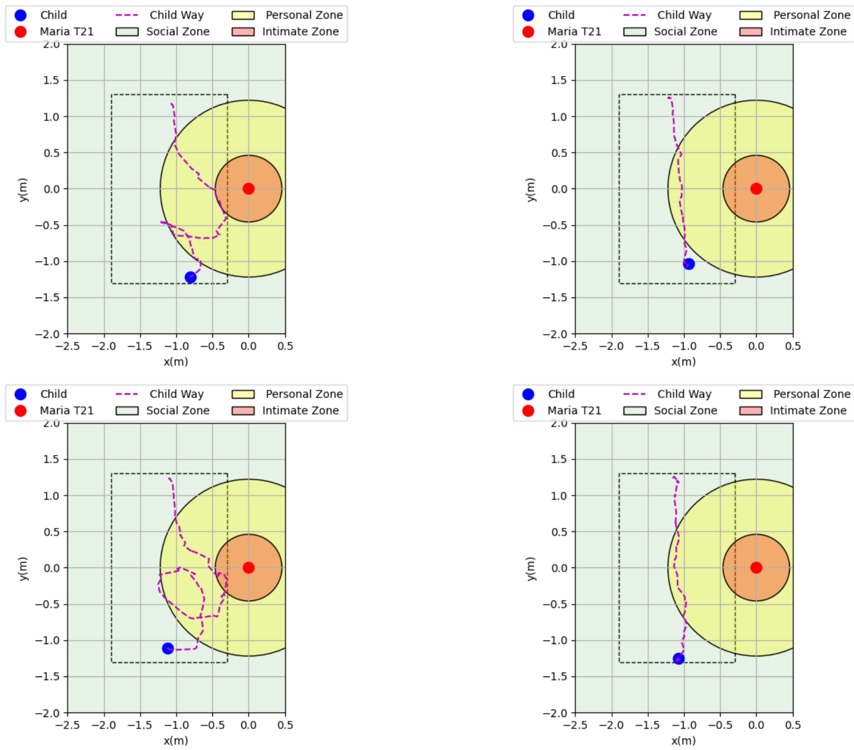


Figura 74 – K8 performance in the first and last week

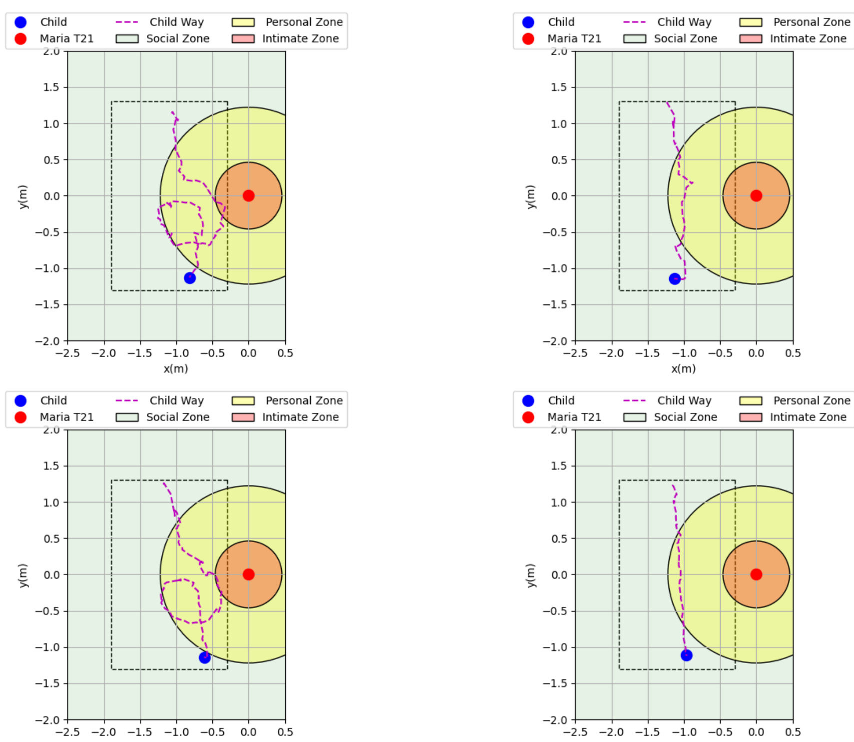


Figura 75 – K9 performance in the first and last week

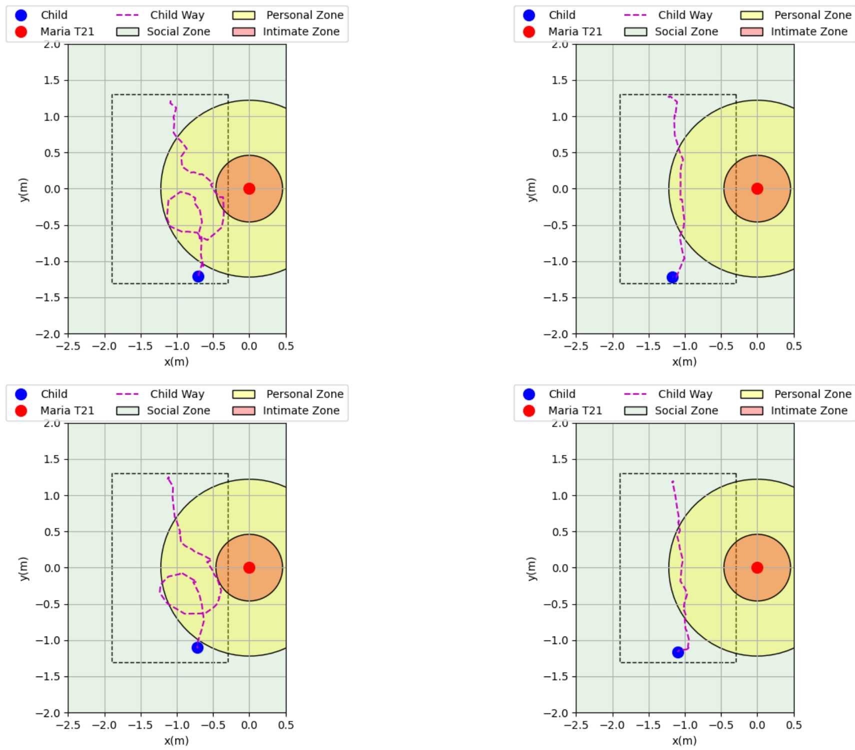


Figura 76 – K10 performance in the first and last week

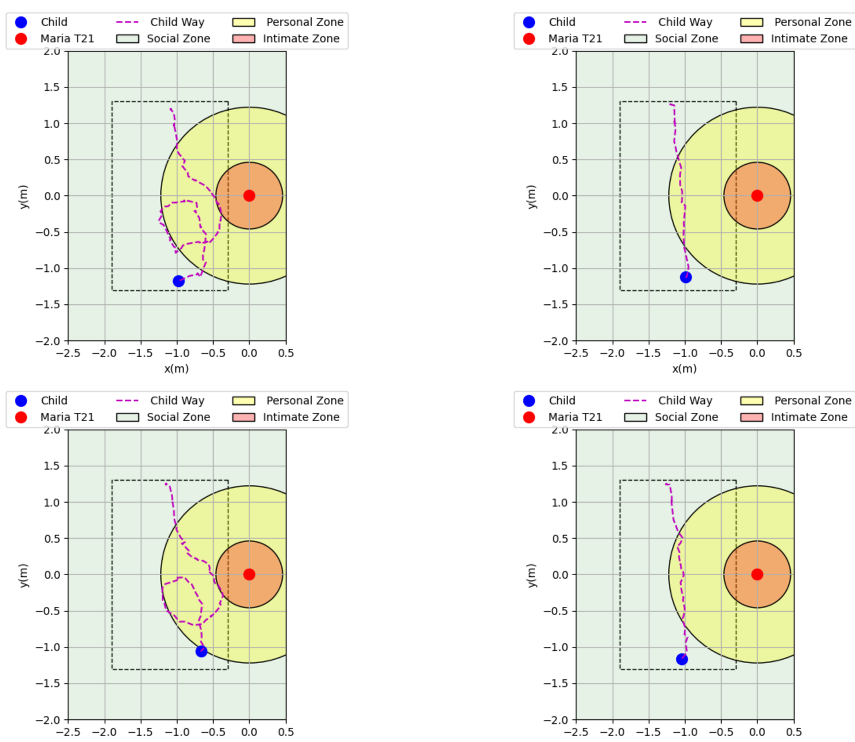


Figura 77 – K11 performance in the first and last week

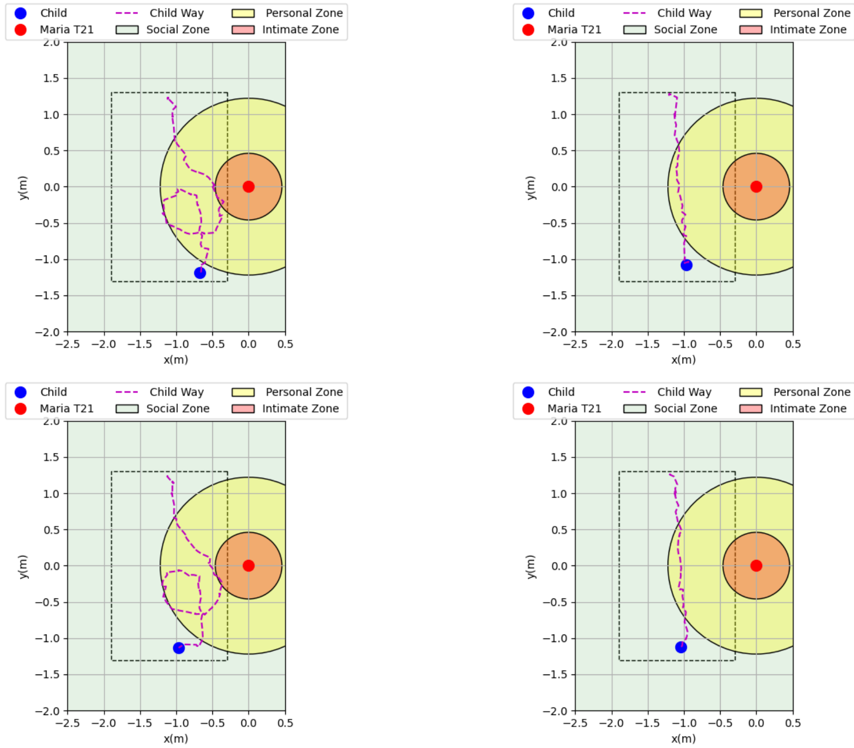


Figura 78 – K12 performance in the first and last week

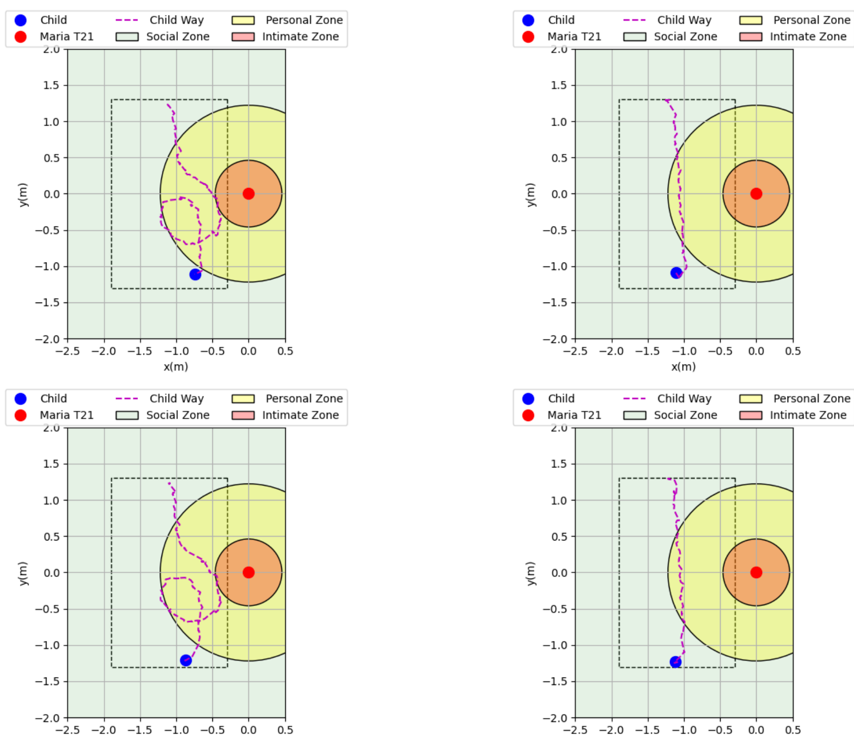


Figura 79 – K13 performance in the first and last week

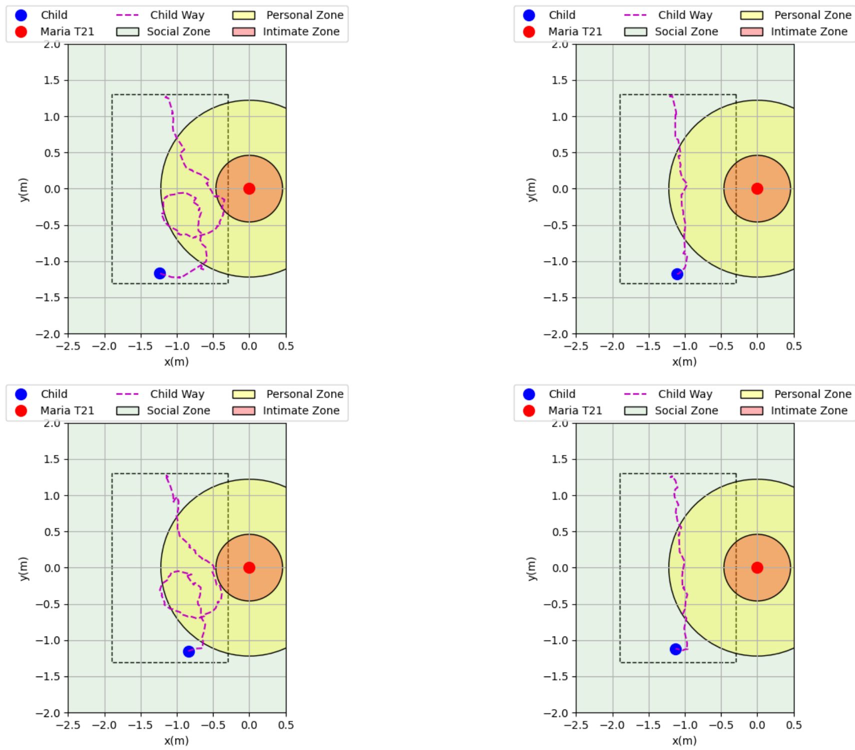


Figura 80 – K14 performance in the first and last week

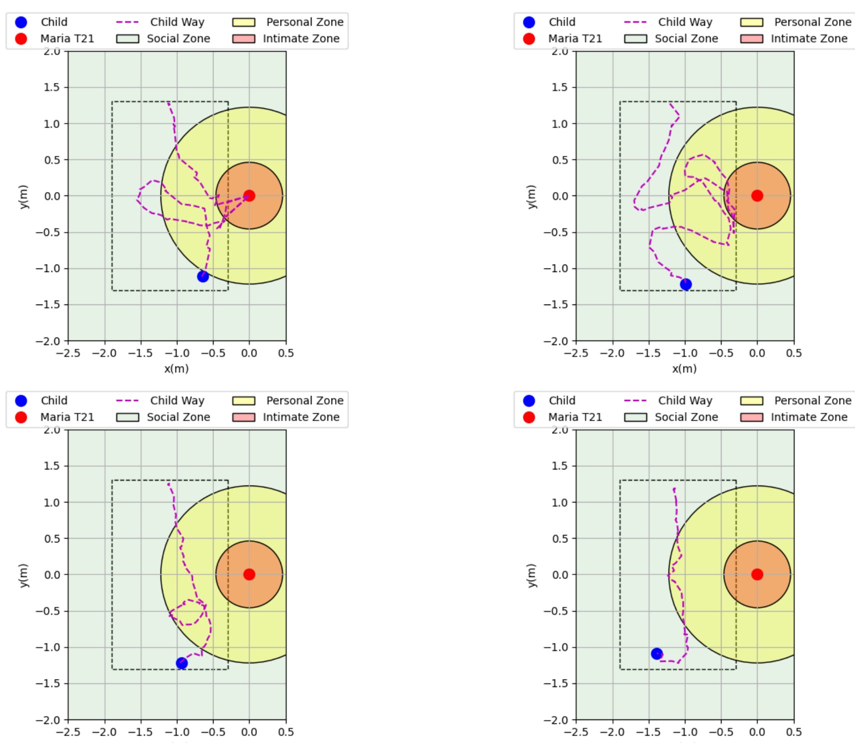


Figura 81 – K15 performance in the first and last week

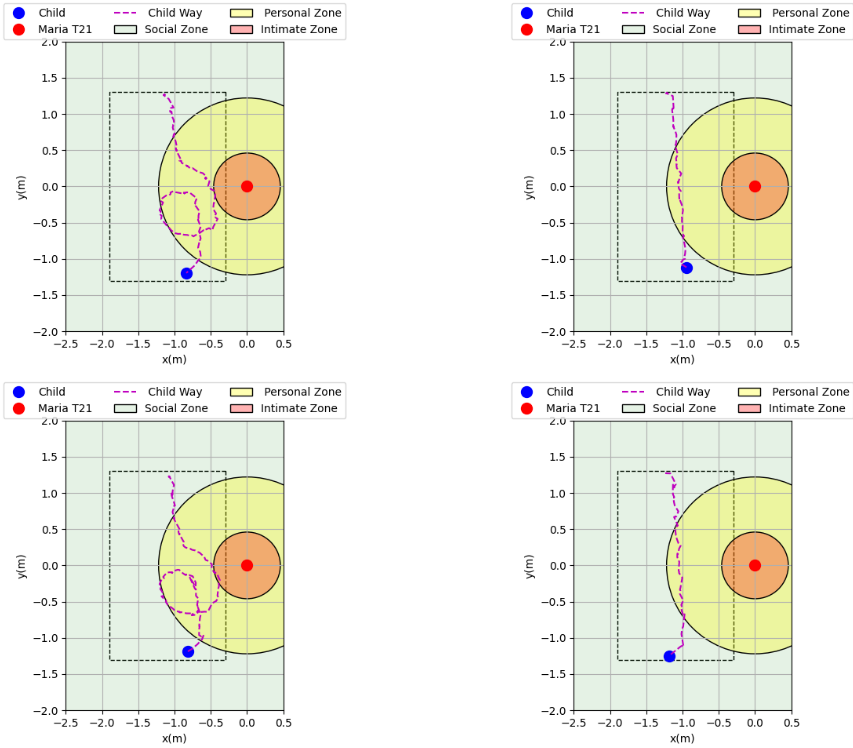


Figura 82 – K16 performance in the first and last week

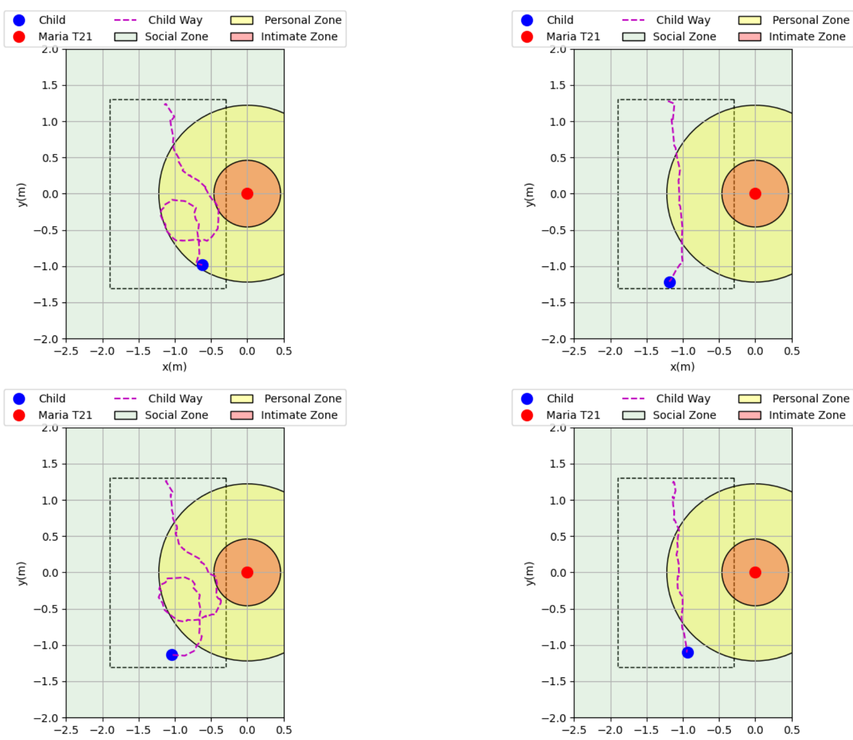


Figura 83 – K17 performance in the first and last week

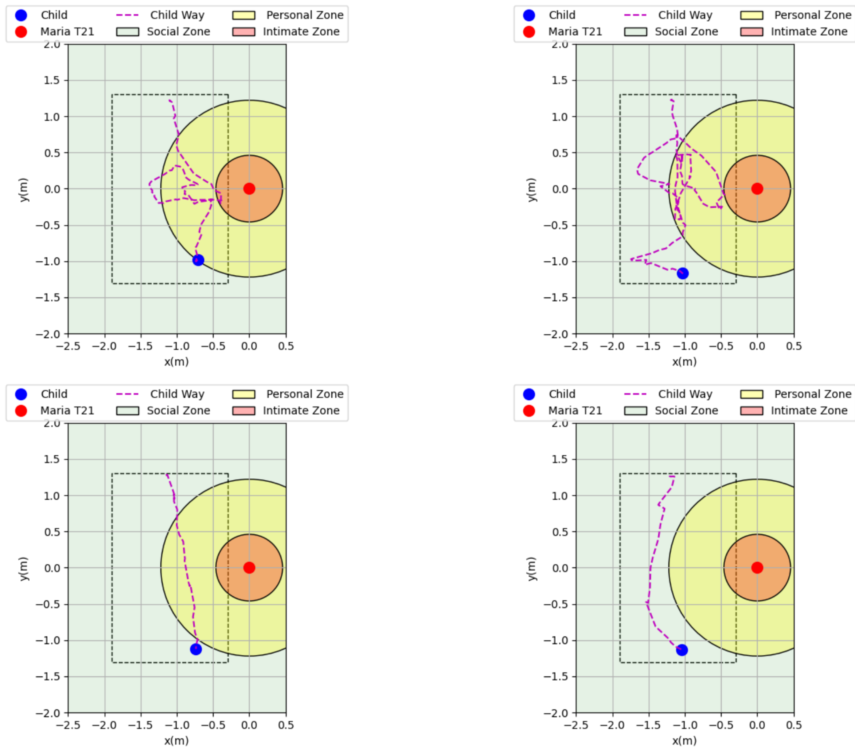


Figura 84 – K18 performance in the first and last week

The results obtained in the balance phases of the serious game CrossKids indicate a significant correlation between the participants' performance and their individual cognitive characteristics. It was observed that children with greater attention capacity and better motor coordination tend to show better and more consistent progress in the balance phases. On the other hand, children with difficulties in cognitive skills, such as working memory and inhibitory control, demonstrated slower progress, requiring more time and attempts to reach similar levels of stability. These findings suggest that cognitive skills play a crucial role in learning and developing the motor competencies necessary for balance, highlighting the importance of personalized approaches in using serious games to optimize learning and motor development in children with different cognitive profiles.

6.2.3 Functional Module

The Raining Food SG was used with 8 participants (K1, K4, K9, K11, K13, K16, K17, K18) over a period of 4 weeks. Prior to the start of the game, the facilitators engaged in conversations with the participants about the importance of healthy eating and reviewed the daily meals. During the game and before each new level, the names of the meals and the respective foods to be collected were emphasized. Furthermore, the incorrect collection and disposal of foods were presented as wasteful and discouraged. In this way, as the children played, they were repeatedly exposed to meals, some common types of foods from each of them, and introduced to concepts like wastage. Figure 85 depicts some participants during the execution of Raining Food.

Figura 85 – Children playing Raining Food

The key indices for analyzing this SG include the number of foods collected erroneously, which indicates the difficulty in associating foods with specific meals, and also reflects potential challenges in response time, association, and movement, as well as the time taken to complete all levels. Figures 86 to 89 present the number of foods collected erroneously in each level and the total time spent to complete the game for each participant over the 4 weeks. The types of modulation (A, B, C, D, E, F) applied in each level are specified as detailed in section 4.6.1.

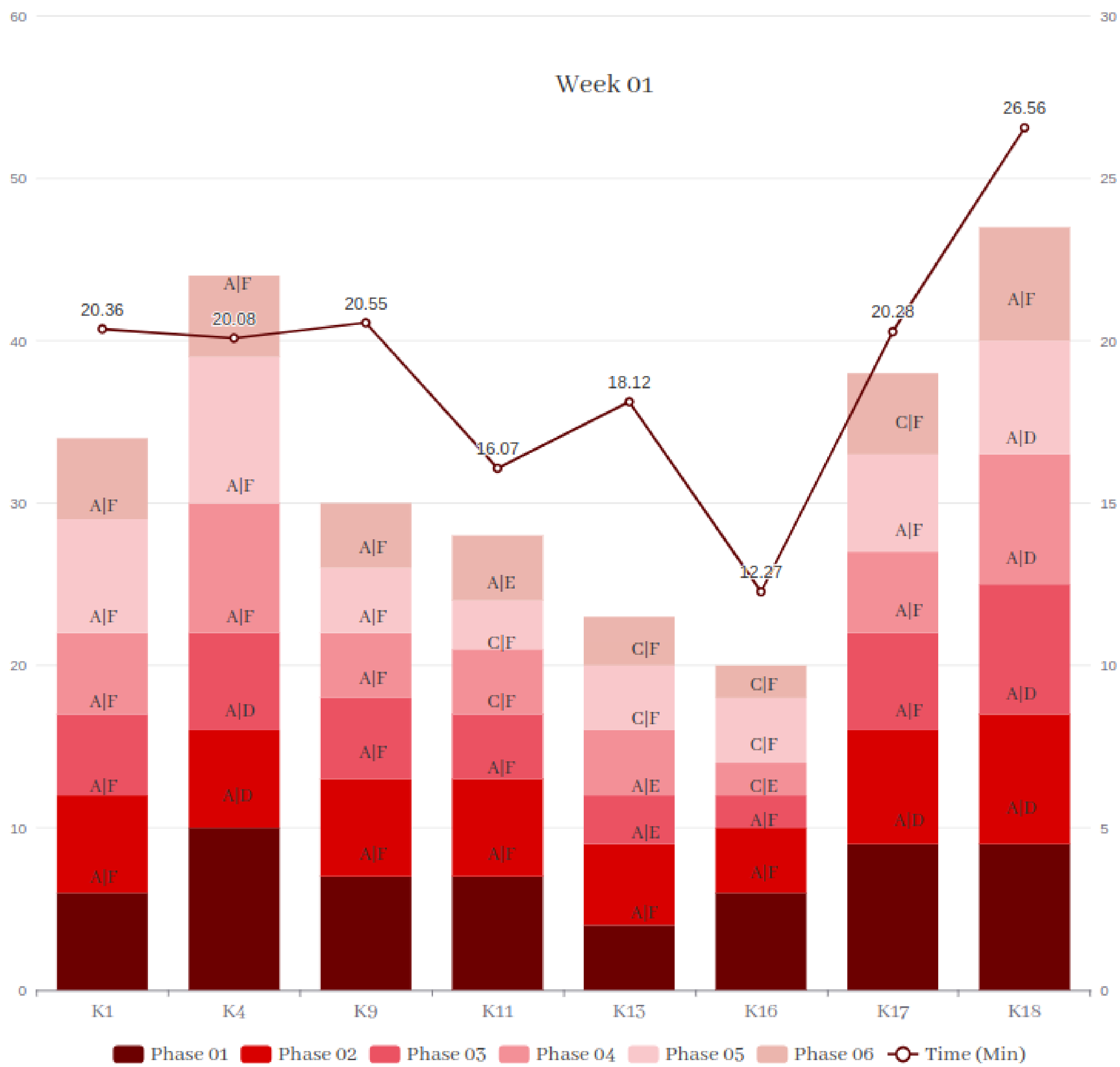


Figura 86 – Mistakes in Food Collection by Phase and Total Execution Time in Week 01

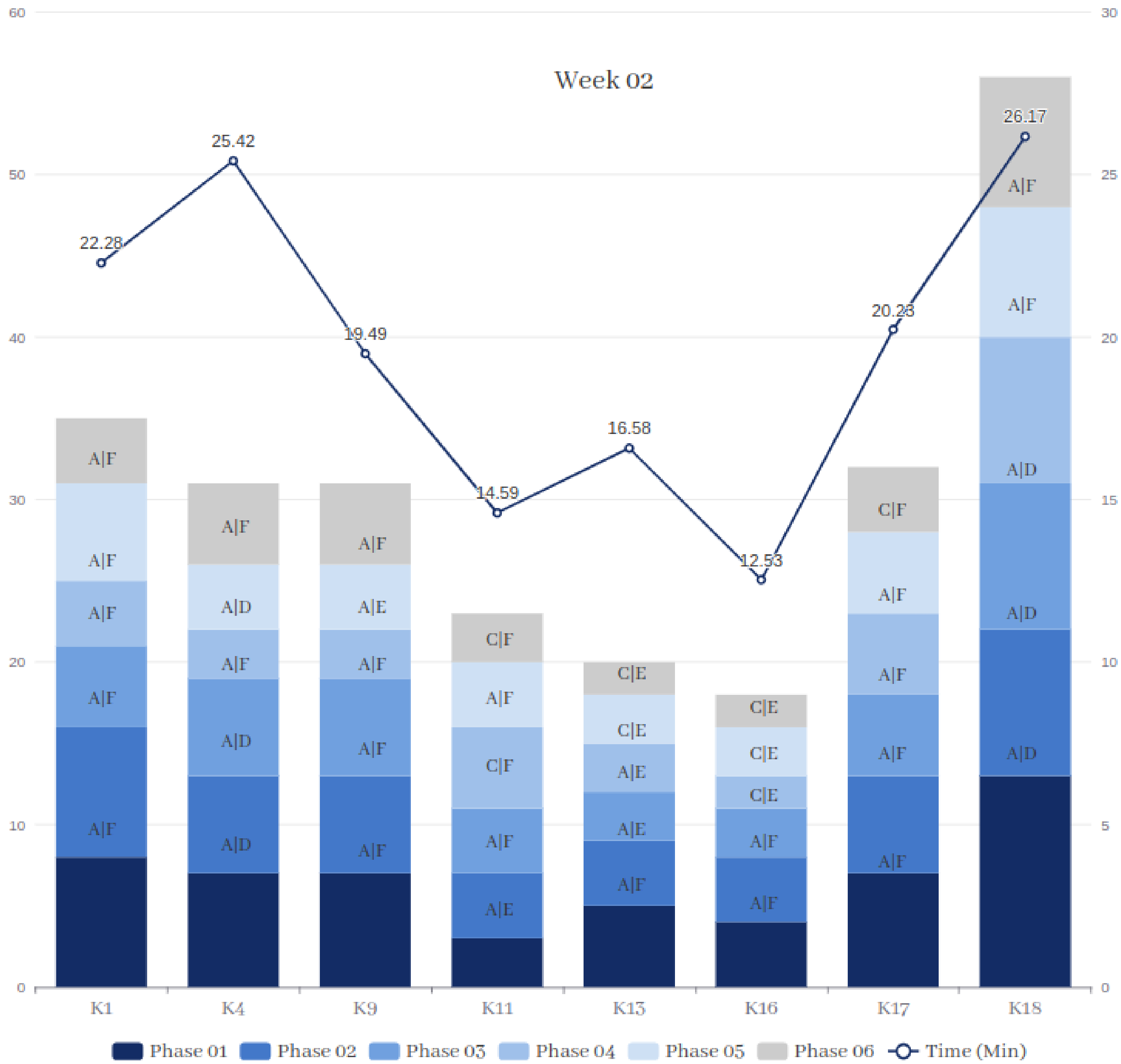


Figura 87 – Mistakes in Food Collection by Phase and Total Execution Time in Week 02

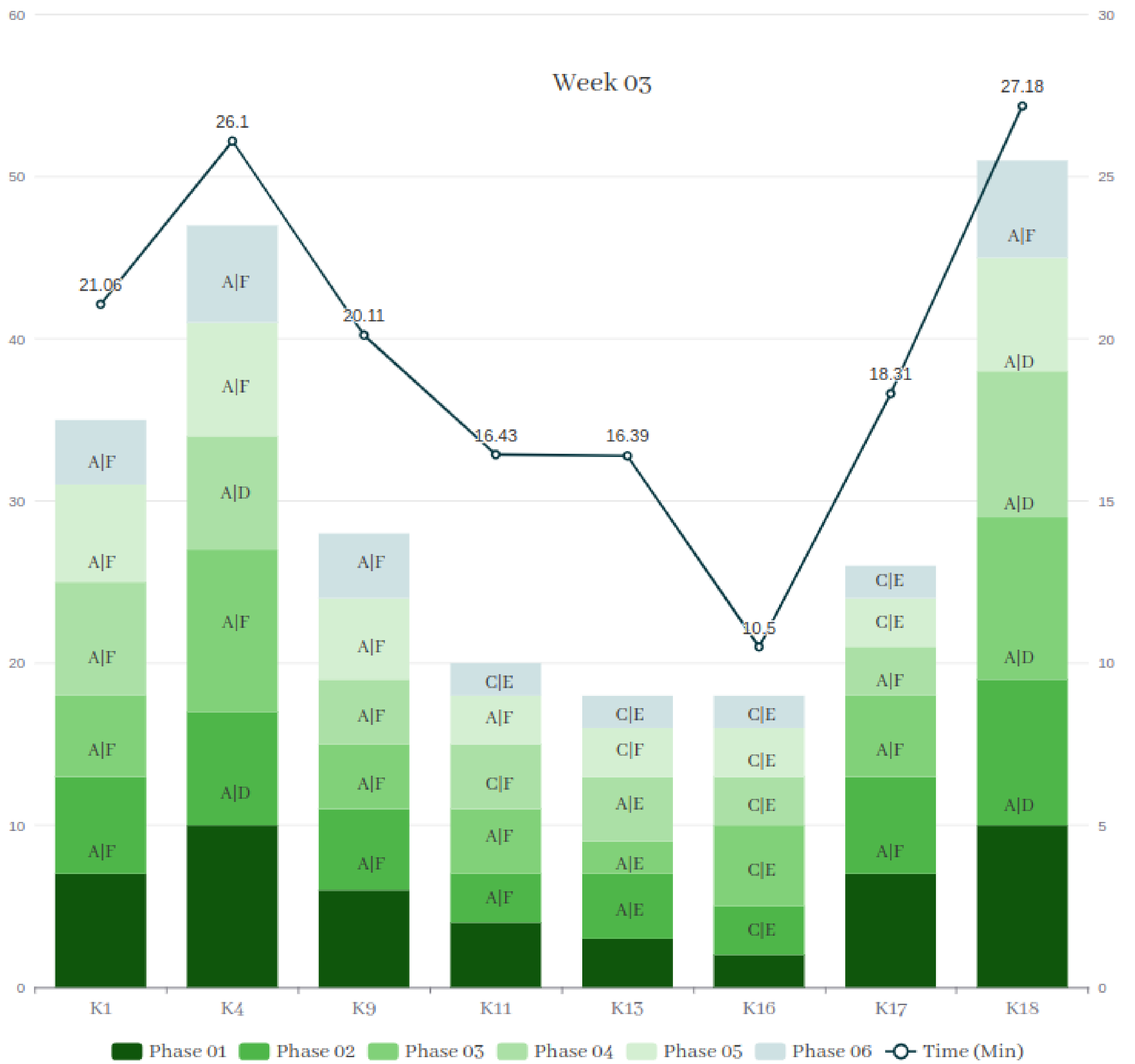


Figura 88 – Mistakes in Food Collection by Phase and Total Execution Time in Week 03

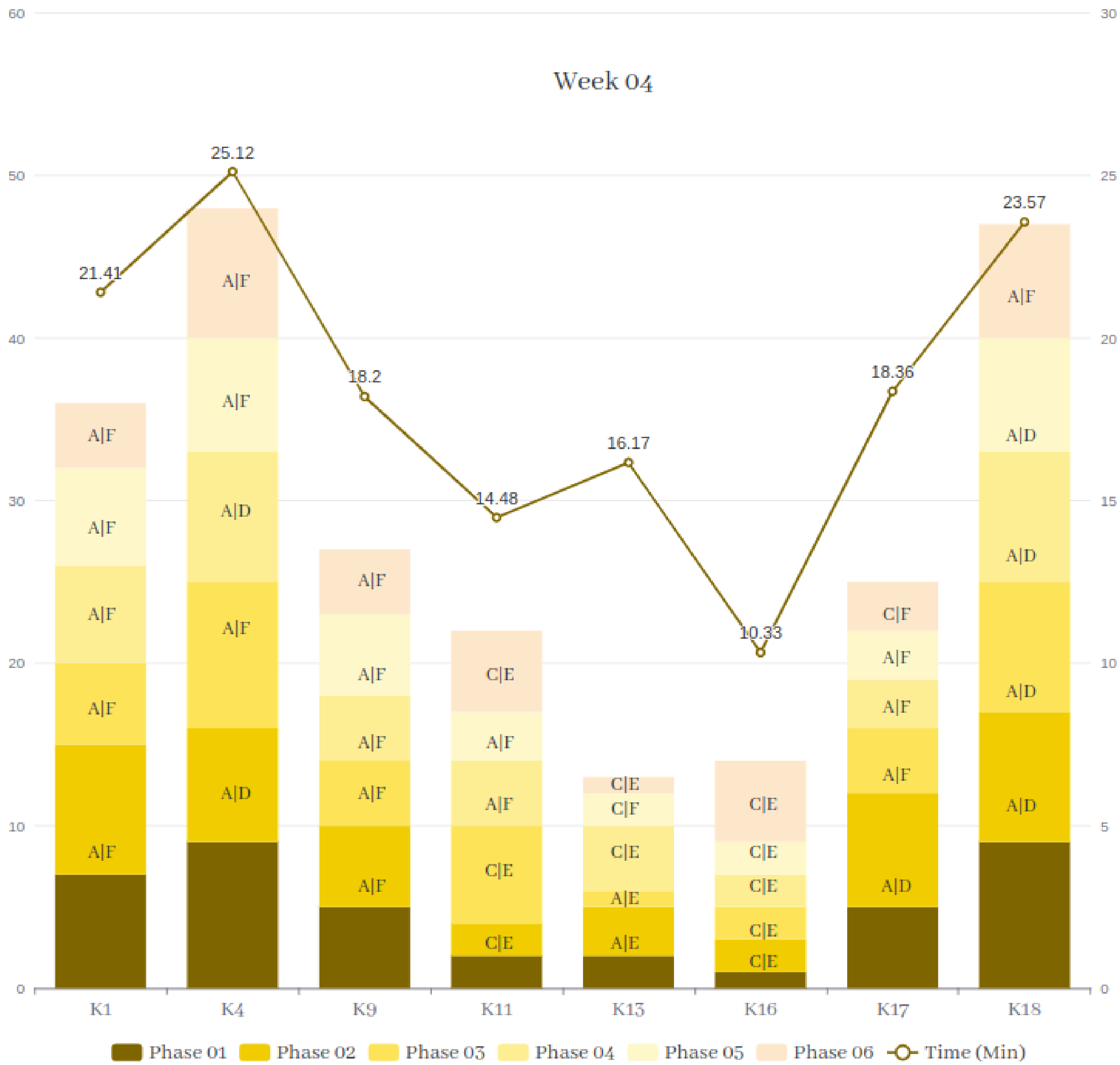


Figura 89 – Mistakes in Food Collection by Phase and Total Execution Time in Week 04

The Bricks Breaker SG was employed without modulation for two weeks in a test version and used for GAS scale evaluation and participant familiarization (Figure 90). Its finalized version with DDA features was executed by the 18 participants over 4 weeks. The data represented in Table 23 correspond to the 4 weeks of the game executed with DDA features (Figure 91).

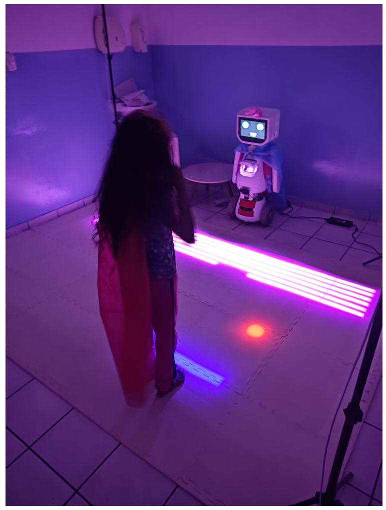


Figura 90 – Child receiving guidance on how to play Bricks Breaker

Figura 91 – Children playing Bricks Breaker

Table 23 – Performance Data Bricks Breaker

Participants	Week 1			Week 2			Week 3			Week 4		
	Platform Size	Speed	Time	Platform Size	Speed	Time	Platform Size	Speed	Time	Platform Size	Speed	Time
K1	8	3.75	01:49	6	5.00	02:27	6	3.75	02:38	8	3.75	02:23
K2	6	3.75	02:12	8	3.75	02:18	6	5.00	02:37	8	3.75	03:00
K3	6	5.00	03:05	6	3.75	03:02	6	5.00	02:07	6	5.00	02:14
K4	8	3.75	01:15	8	3.75	00:51	8	3.75	01:41	8	3.75	00:56
K5	6	5.00	03:03	6	3.75	01:57	6	5.00	02:13	6	5.00	02:49
K6	8	3.75	01:09	6	3.75	01:32	6	5.00	01:39	6	5.00	01:28
K7	8	3.75	00:48	8	3.75	00:57	8	3.75	01:19	8	3.75	01:23
K8	8	3.75	01:14	8	3.75	01:34	8	3.75	01:15	8	3.75	00:46
K9	8	3.75	00:52	6	3.75	01:29	6	3.75	02:01	6	5.00	02:17
K10	8	3.75	01:32	6	3.75	01:35	6	5.00	01:22	6	3.75	02:17
K11	6	5.00	02:12	6	5.00	02:23	6	3.75	01:25	6	5.00	03:23
K12	6	5.00	02:20	6	5.00	02:50	6	3.75	02:58	6	5.00	03:12
K13	6	5.00	01:45	8	5.00	01:39	6	5.00	02:28	6	5.00	02:56
K14	8	3.75	01:02	6	3.75	01:36	6	3.75	00:49	8	3.75	01:44
K15	8	3.75	01:18	8	3.75	01:33	8	3.75	01:19	8	3.75	00:48
K16	6	5.00	02:26	6	5.00	03:04	6	5.00	02:29	6	5.00	03:47
K17	6	5.00	03:23	6	5.00	03:22	6	5.00	03:14	6	5.00	02:25
K18	8	3.75	01:30	8	3.75	00:55	8	3.75	01:31	8	3.75	01:27
Average	6.89	4.17	01:57	6.33	4.12	01:55	6.44	4.18	02:00	6.56	4.23	01:57

Figure 92 shows the individual total of bricks collected in the session with the highest count for each of the 4 weeks.

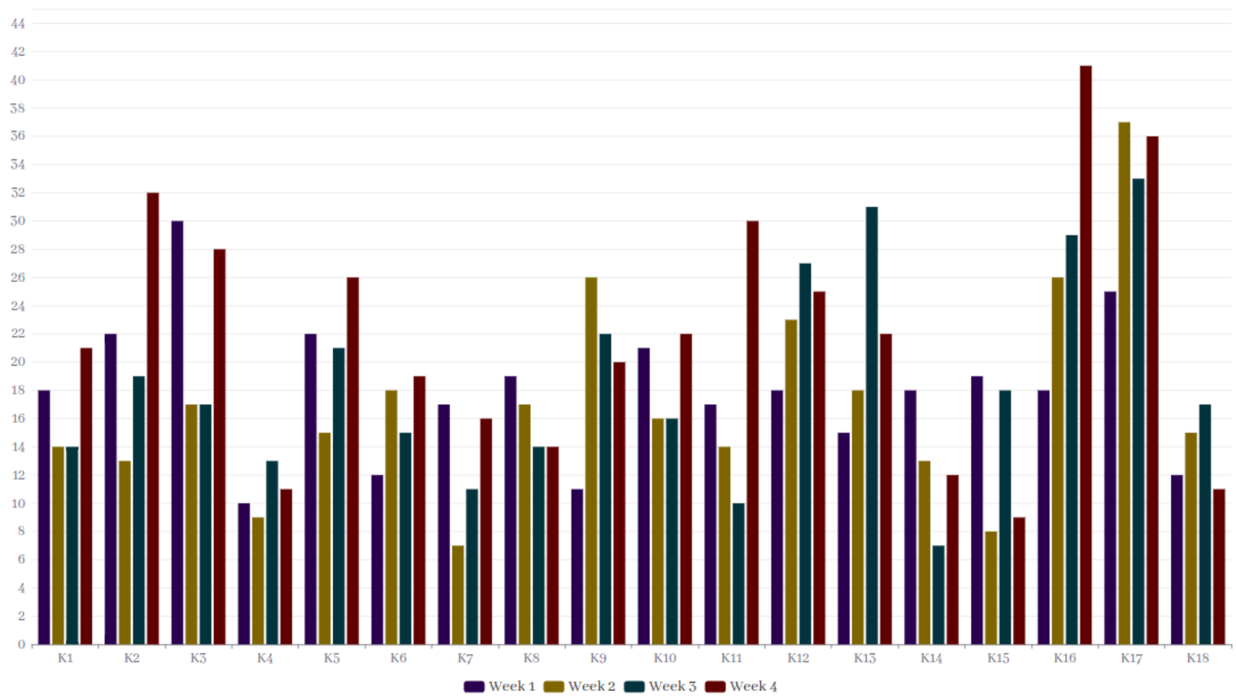


Figura 92 – Total bricks collected per week in SG Bricks Breaker

The Tracing activity was conducted over 8 weeks, during which different drawings with various strokes and complexities were used. Figure 93 displays some of the drawings created by children using pens.

Figura 93 – Children playing Tracing with pen

Tracing was also performed using glue in squeeze bottles to exercise finger strength and pincer grip. Figure 94 displays some of the drawings made with glue. The higher occurrence of dots and flaws highlights the difficulty in maintaining constant pressure on the squeeze bottle.

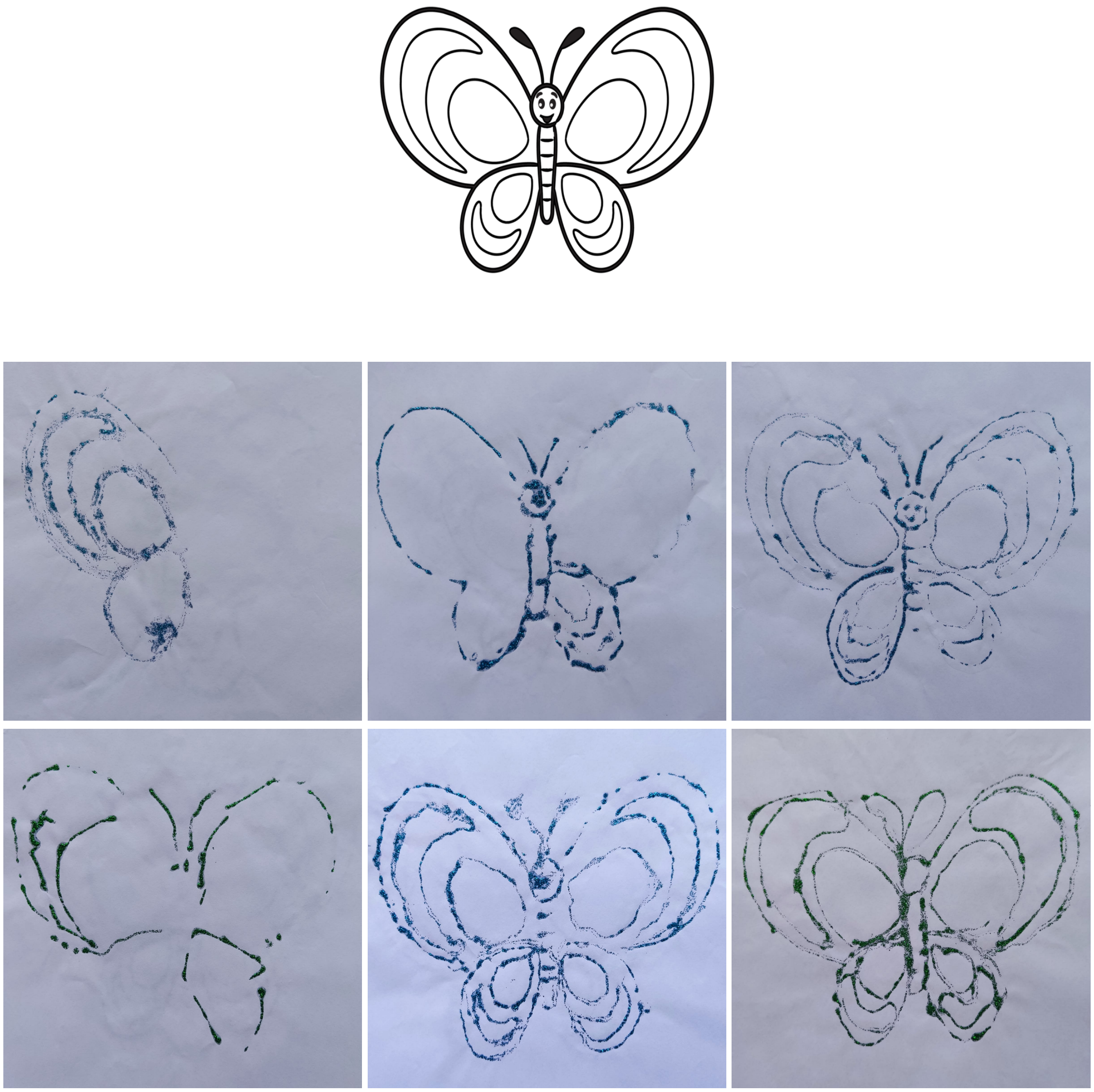


Figura 94 – Children playing Tracing with glue

In the Tracing dynamic, the GAS was applied in the first and last weeks to evaluate performance considering three objectives: Quality in following the lines of the projected drawings; Consistency and continuity in outlining the drawings using glue; Quality of the final drawing outcome. The obtained values are presented in Table 24.

Tracing is a highly beneficial activity for refining fine motor coordination, crucial for tasks like writing, drawing, and handling small objects. It also enhances skills like the pincer grasp and concentration, vital for child development (ZHANG et al., 2022). Additionally, it fosters creativity by allowing children to draw over projections with various colors, while cognitive processes involved in recognizing shapes and colors contribute to cognitive and

Table 24 – GAS Dynamic Tracing*

Participants	GAS week 1	GAS Week 8
K1	31.76	45.44
K2	45.44	59.12
K3	45.44	63.68
K4	31.76	36.32
K5	50.00	68.24
K6	36.32	59.12
K7	36.32	45.44
K8	36.32	50.00
K9	40.88	63.68
K10	36.32	54.56
K11	36.32	50.00
K12	40.88	50.00
K13	45.44	59.12
K14	50.00	63.68
K15	22.64	31.76
K16	40.88	59.12
K17	40.88	50.00
K18	45.44	50.00

* The data was analyzed using the paired t-test, with $p < 0.01$.

visual perception development. Interacting with the robot during tracing encourages social engagement, aiding children who may struggle in this area. As children progress, they build self-esteem and confidence, finding fulfillment in completing drawings. Moreover, the sensory aspects of the activity, utilizing different materials like pencils and glitter glue, provide valuable tactile stimuli, particularly beneficial for children with sensory challenges (SHAFIE, 2022).

Analyzing the data presented in Table 24, it is evident that there is a notable improvement in GAS scores for most participants from week 1 to week 8. This improvement suggests that the participants have benefitted from engaging in the Tracing dynamic, demonstrating enhanced skills and performance over time.

Participant K5 shows a substantial improvement, with a GAS score increasing from 50.00 in week 1 to 68.24 in week 8. This significant increase indicates that participant K5 has made considerable progress in quality, consistency, and overall performance in tracing activities over the course of the study. Conversely, participant K15 demonstrates a more modest evolution, with a GAS score rising from 22.64 in week 1 to 31.76 in week 8. While there is improvement, it is not as pronounced as some other participants, suggesting that participant K15 may have faced challenges or required more time to develop their tracing skills compared to others.

These results highlight the variability in participant's responses to the Tracing dynamic and underscore the importance of individualized approaches to intervention and support. While some participants exhibit substantial growth, others may progress more gradually or face challenges that impede their development. Understanding these variations can inform tailored strategies to optimize outcomes and support each participant's unique needs and abilities.

Super Hero dynamic was carried out by 8 children (K1, K4, K9, K11, K13, K16, K17, K18) over the course of 4 weeks (Figure 95). The selection of participants was made considering the result of the initial assessment for the presence of any type of difficulty in bending or performing manual tasks. In addition to the main objective of teaching tying knots and promoting independence in the dressing process, it is believed that this activity can bring several other therapeutic benefits. Firstly, as children manipulate knots to secure the superhero cape, they enhance fine motor coordination, crucial for tasks requiring hand and finger dexterity. Additionally, handling objects like capes fosters greater body awareness and proprioception, aiding safe movement. Moreover, engaging in imaginative play as superheroes stimulates creativity and problem-solving skills. In the Super Hero dynamic, the GAS was applied in the first and fourth weeks to assess performance considering three objectives: Autonomy and skill in holding the string with two fingers of each hand (pincer grip function); Ability to tie the knot; Ability to make the final loop. The obtained values are presented in Table 25.

Table 25 – GAS Dynamic Super Hero*

Participants	GAS week 1	GAS Week 4
K1	40.88	50.00
K4	40.88	40.88
K9	36.32	54.56
K11	36.32	50.00
K13	40.88	54.56
K16	40.88	63.68
K17	54.56	59.12
K18	40.88	40.88

* The data was analyzed using the paired t-test, with $p < 0.01$.

Figura 95 – Dynamic Super Hero

Analyzing the GAS data, it is apparent that there are varying degrees of progress among the participants over the 4-week period. For example, participant K17 exhibited a substantial improvement, with a GAS score rising from 54.56 in week 1 to 59.12 in week 4. This increase suggests notable advancements in autonomy, knot-tying ability, and loop-making proficiency, reflecting positive outcomes from engaging in the Super Hero dynamic.

On the other hand, participant K4 maintained the same GAS score of 40.88 from week 1 to week 4, indicating a lack of significant progress in the targeted objectives over the intervention period. This stagnation may necessitate further exploration into individualized strategies or adjustments to better support participant K4's development in tying knots and enhancing dressing independence.

It's important to note the overall positive trend in GAS scores across the participants, suggesting that the Super Hero dynamic effectively contributed to the targeted therapeutic goals. The significant variability in individual progress underscores the importance of personalized approaches and ongoing assessment to tailor interventions to each participant's unique needs and abilities.

This occupational therapy activity with superhero capes and robot involvement demonstrates how technology can be a powerful tool to assist in therapeutic interventions. It combines learning and fun, making the process of developing motor and emotional skills a positive and enriching experience for children (Figure 96).

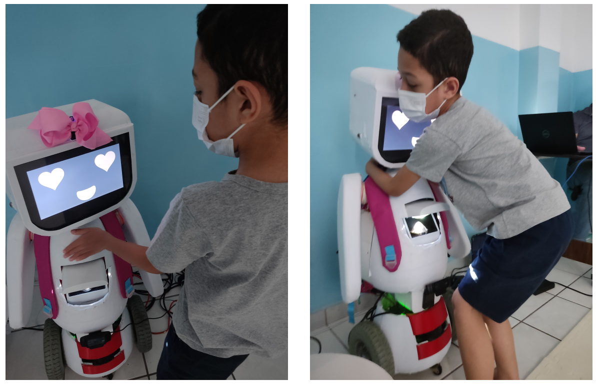


Figura 96 – Approaching and showing affection

7 Conclusion

Although the results of this research were promising, the preliminary experiments highlighted the need for more dynamic, specific, and flexible activities throughout the weeks of intervention. We observed a decline in children's interest in repetitive and slightly varied activities, highlighting the importance of personalizing tasks to maintain engagement. Furthermore, applying a uniform protocol to all children, without adapting to individual characteristics and specific deficits during the initial assessment, proved to be a significant limitation.

This study investigated the feasibility of employing the SAR MARIA T21 to administer cognitive, physical, and functional SGs with individuals diagnosed with ASD, in order to practice clinical principles based on the ABA methodology, specifically utilizing the DDT and PRT approaches.

In particular, MARIA T21 was utilized in a protocol involving 18 children with ASD. The quality of interaction was monitored through established assessment scales, applied prior to interventions, with the aim of enhancing the understanding of the autistic spectrum characteristics of each participant. This approach allowed for greater personalization of interventions, the observation of skill development in participants, and the exploration of the relationship between scale results and the SGs implemented in the protocols.

Specifically, MARIA T21 was capable of providing performance monitoring for the participants, offering incentives, stimuli, corrections, and suggestions, while applying SGs that were adaptable to the physical, cognitive, and functional abilities of the participants.

The results demonstrated that MARIA T21 successfully administered the SGs to the children, as the information provided by the scales aligned with their performance in the games. Additionally, the presence of DDA for customizing the characteristics of SGs in accordance with the ABA PRT methodology was statistically significant.

These findings are consistent with previous literature on the application of the ABA DTT methodology (BEGUM et al., 2015; WARREN et al., 2015; SALVADOR et al., 2016; FENG et al., 2018) and underscore the potential of using SARs in clinical practice, particularly within the ABA PRT framework, to personalize interventions based on individual characteristics and learning pace. In the realm of healthcare, this work can be utilized to evaluate the relationship between the costs of the robot and SGs and the outcomes in terms of improvements and broadened application of ABA.

The results obtained in this study offer numerous avenues for further system development and value generation. Findings open up the possibility of time-saving for healthcare professionals and greater customization of interventions for children with ASD, thereby minimizing potential frustrations resulting from excessive or insufficient demands in therapeutic activities. Furthermore, a robot that records SG data for a children with ASD at different time points generates valuable data that clinicians can leverage in follow-up consultations.

Understanding and taking into account the participant's level of interest and challenge during an intervention can increasingly contribute for adapting SAR interactions to be more natural and user-friendly. The use of SARs to administer SGs with DDA children with ASD has the potential to enhance the acceptance of ABA, which in Brazil, is the only methodology covered by the Unified Health System.

It is worth commenting that in accordance with Fonseca (1995), the psychomotor profile identifies both strengths and learning difficulties, allowing for specific interventions. In this study, it was searched to observe correlations between motor difficulties in children with ASD and difficulties observed in the cognitive and/or functional modules through the results of the motor module.

7.1 Limitations and Future Work

Despite the contributions of this study, some limitations should be acknowledged. First, the limited sample size of 18 children with ASD may restrict the generalizability of the results. Furthermore, the absence of a control group prevents direct comparison of the effects of the intervention with other therapeutic approaches, although comparative analysis considering the autistic spectrum may not be feasible or appropriate. It is also important to consider the variation in the degree of engagement and particular affinities of the participants, which may have influenced the results.

Future studies are expected to be conducted with larger samples and the inclusion of control groups to validate the findings and explore the comparative effectiveness of the use of the robot MARIA T21. In addition, it is also intended to investigate the application of adaptive protocols that consider the individual preferences and level of interest of each child whit ASD over time, to increase the effectiveness of the interventions. Additionally, studies that explore the long-term impact of the use of SARs on the evolution of motor, cognitive and functional skills of children with ASD may provide valuable insights for the continued development of this technology.

7.2 Publications

During this research, the following complete articles were published in Journals

- **VALTER DA SILVA FREITAS, ÉBERTE**; ANTONIO CAMPOS PANCERI, JOÃO; DA LUZ SCHREIDER, SHEILA; MARIA DE OLIVEIRA CALDEIRA, ELIETE; FREIRE BASTOS FILHO, TEODIANO. Cognitive Serious Games Dynamically Modulated as a Therapeutic Tool for Applied Behavior Analysis Therapy in Children with Autism Spectrum Disorder. INTERNATIONAL JOURNAL: EMERGING TECHNOLOGIES IN LEARNING, v. 19, p. 80-92, 2024.
- PANCERI, JOÃO ANTONIO CAMPOS; **FREITAS, ÉBERTE**; DE SOUZA, JOSIANY CARLOS; DA LUZ SCHREIDER, SHEILA; CALDEIRA, ELIETE; BASTOS, TEODIANO FREIRE. A New Socially Assistive Robot with Integrated Serious Games for Therapies with Children with Autism Spectrum Disorder and Down Syndrome: A Pilot Study. SENSORS, v. 21, p. 8414, 2021.
- DA LUZ SCHREIDER, SHEILA; DE SOUZA, JOSIANY CARLOS; DA SILVA FREITAS, **ÉBERTE VALTER**; PANCERI, JOÃO ANTONIO CAMPOS; DE OLIVEIRA CALDEIRA, ELIETE MARIA; BASTOS-FILHO, TEODIANO FREIRE. Psychomotor intervention through serious games in children and adolescents with autism spectrum disorder using a therapeutic robot. RESEARCH ON BIOMEDICAL ENGINEERING, v. 1, p. 1, 2024.

Published book chapters

- PANCERI, J. A. C.; **FREITAS, E. V. S.**; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS-FILHO, T. F. Proposal of a New Socially Assistive Robot with Embedded Serious Games for Therapy with Children with Autistic Spectrum Disorder and Down Syndrome. In: Teodiano Freire Bastos-Filho; Eliete Maria de Oliveira Caldeira; Anselmo Frizera-Neto. (Org.). XXVII Brazilian Congress on Biomedical Engineering. 1ed.Switzerland: Springer International Publishing, 2021, v. 83, p. 1865-1870.

Complete works published in Conference Proceedings

- **FREITAS, E. V. S.**; PANCERI, J. A. C.; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS-FILHO, T. F. MEMÔ THE GAME: SERIUS GAME FOR DEVELOPMENT OF MEMORIZATION IN CHILDREN WITH AUTISTIC SPECTRUM DISORDER. In: XXVIII Congresso Brasileiro de Engenharia Biomédica, 2022, Florianópolis, SC. XXVII Brazilian Congress in Biomedical Engineering, 2022.
- TEIXEIRA, L. S.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS-FILHO, T. F. PROPOSAL OF A PARALANGUAGE SYSTEM WITH CLOUD PROCESSING FOR A SOCIALLY ASSISTIVE ROBOT. In:

XXVIII Congresso Brasileiro de Engenharia Biomédica, 2022, Florianópolis, SC. XXVII Brazilian Congress in Biomedical Engineering, 2022.

- PANCERI, J. A. C.; **FREITAS, E. V. S.**; SCHREIDER, S. L.; SOUZA, J. C.; CALDEIRA, E. M. O.; BASTOS-FILHO, T. F. A MULTISENSORIAL SOCIALLY ASSISTIVE ROBOT FOR THERAPIES WITH CHILDREN WITH AUTISM SPECTRUM DISORDER AND DOWN SYNDROME USING SERIOUS GAMES. In: XXVIII Congresso Brasileiro de Engenharia Biomédica, 2022, Florianópolis, SC. XXVII Brazilian Congress in Biomedical Engineering, 2022.
- NEGRI, Y. R.; PANCERI, J. A. C.; **FREITAS, E. V. S.**; SCHREIDER, S. L.; CALDEIRA, E.; BASTOS-FILHO, T. F. PROPOSAL OF SERIOUS GAMES FOR A SOCIALLY ASSISTIVE ROBOT BASED ON EYE CONTACT AND VISUAL ATTENTION OF CHILDREN WITH AUTISM SPECTRUM DISORDER. In: XXVIII Congresso Brasileiro de Engenharia Biomédica, 2022, Florianópolis, SC. XXVII Brazilian Congress in Biomedical Engineering, 2022.
- SCHREIDER, S. L.; SOUZA, J. C.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; CALDEIRA, E. M. O.; BASTOS-FILHO, T. F. INTERVENÇÃO PSICOMOTORA POR MEIO DE JOGOS SÉRIOS EM CRIANÇAS E ADOLESCENTES COM TRANSTORNO DO ESPECTRO AUTISTA UTILIZANDO ROBÔ TERAPÊUTICO. In: XXVIII Congresso Brasileiro de Engenharia Biomédica, 2022, Florianópolis, SC. XXVII Brazilian Congress in Biomedical Engineering, 2022.
- SCHREIDER, S. L.; SOUZA, J. C.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; CONTRERAS, A. M.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. PROPOSAL OF GAMES FOR CHILDREN AND TEENAGERS WITH DOWN SYNDROME APPLIED TO A SOCIALLY ASSISTIVE ROBOT. In: Simpósio de Engenharia Biomédica, 2021. XIII Simpósio de Engenharia Biomédica. Uberlândia, 2021.
- SOUZA, J. C.; SCHREIDER, S. L.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; CONTRERAS, A. M.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. PROPOSAL OF SERIOUS GAMES AND ASSISTIVE ROBOT TO AID THERAPIES OF CHILDREN WITH AUTISM SPECTRUM DISORDER. In: Simpósio de Engenharia Biomédica, 2021, Uberlândia. XIII Simpósio de Engenharia Biomédica. Uberlândia, 2021.
- SCHREIDER, S. L.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; CALDEIRA, E. M. O.; BASTOS-FILHO, T. F. PROPOSTA DE JOGOS PARA CRIANÇAS E ADOLESCENTES COM SÍNDROME DE DOWN APLICADOS AO ROBÔ SOCIALMENTE ASSISTIVO. In: XI - Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad, 2021. Anales del XI Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad, 2021.
- PANCERI, J. A. C.; **FREITAS, E. V. S.**; SOUZA, J. C.; SCHREIDER, S. L.; CON-

TRERAS, A. M.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. UN NUEVO ROBOT DE ASISTENCIA SOCIAL CON JUEGOS SERIOS INTEGRADOS PARA TERAPIAS CON NIÑOS CON TRASTORNO DEL ESPECTRO AUTISTA Y SÍNDROME DE DOWN. In: IV Congreso Internacional de Tecnología y Turismo para la Diversidad, 2021. Memorias del Un Nuevo Robot de Asistencia Social con Juegos Serios Integrados para Terapias con Niños con Trastorno del Espectro Autista y Síndrome de Down. Madri: ONCE, 2021. v. 1. p. 1-10.

- PANCERI, J. A. C.; **FREITAS, E. V. S.**; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. PROPOSAL OF A NEW SOCIALLY ASSISTIVE ROBOT WITH EMBEDDED SERIOUS GAMES FOR THERAPY WITH CHILDREN WITH AUTISTIC SPECTRUM DISORDER AND DOWN SYNDROME. In: XXVII Congresso Brasileiro de Engenharia Biomédica, 2020, Vitória. XXVII Brazilian Congress in Biomedical Engineering, 2020. p. 1865-1870.
- **FREITAS, E. V. S.**; PANCERI, J. A. C.; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. RAINING FOOD: SERIOUS GAME FOR NUTRITION EDUCATION THERAPIES IN CHILDREN WITH DISABILITIES. In: XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad, 2023, São Carlos, SP, 2023.
- SCHREIDER, S. L.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. INTERVENÇÃO PSICOMOTORA POR MEIO DE JOGOS SÉRIOS EM CRIANÇAS E ADOLESCENTES COM SÍNDROME DE DOWN UTILIZANDO ROBÔ TERAPÊUTICO. In: XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad, 2023, São Carlos, SP, 2023.
- PANCERI, R. C.; PANCERI, J. A. C.; **FREITAS, E. V. S.**; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. CROSSKIDS: THE SERIOUS GAME DEVELOPED FOR MOTOR DEFICIT THERAPIES IN CHILDREN USING THE SOCIAL ROBOT MARIA T21. In: XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad, 2023, São Carlos, SP, 2023.
- MACIEL, M. C. R.; **FREITAS, E. V. S.**; PANCERI, J. A. C.; SCHREIDER, S. L.; CALDEIRA, E. M. O.; BASTOS FILHO, T. F. TERAPIA ASSISTIDA POR ROBÔ PARA O DESENVOLVIMENTO DE HABILIDADES DE DESEMPENHO E OTIMIZAÇÃO DO DESEMPENHO OCUPACIONAL DE CRIANÇAS COM TRANSTORNO DO ESPECTRO AUTISTA. In: XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad, 2023, São Carlos, SP, 2023.

Submitted and awaiting response

- **VALTER DA SILVA FREITAS, ÉBERTE**; ANTONIO CAMPOS PANCERI, JOÃO; DA LUZ SCHREIDER, SHEILA; MARIA DE OLIVEIRA CALDEIRA, ELIETE;

FREIRE BASTOS FILHO, TEODIANO. Socially Assistive Robot as a Tool for Applied Behavior Analysis Therapy Through Serious Gaming and Dynamic Activities with Autistic Children. INTERNATIONAL JOURNAL: Educational Technology & Society. website: http://www.j-ets.net.

References

AHMED, M. I.; KANNAN, G. Secure end to end communications and data analytics in iot integrated application using ibm watson iot platform. *Wireless Personal Communications*, Springer, v. 120, n. 1, p. 153–168, 2021. 39

ALMEIDA L.; SILVA, D. T. D. S. W. R. S. S. T. S. A. B. M. A. *A Computer Game for Training Children with Autism Spectrum Disorder in the Recognition of Basic Emotions.* [S.l.]: International Journal of Computer Games Technology, 2019. v. 1-16. 10.1155/2019/4384896. 44

ARSHAD, N. I. et al. Robots as assistive technology tools to enhance cognitive abilities and foster valuable learning experiences among young children with autism spectrum disorder. *IEEE Access*, IEEE, v. 8, p. 116279–116291, 2020. 91

ASLAN S.; BALCI, O. *GAMED: Digital educational game development methodology.* [S.l.]: Simulation, 2015. v.91. 307–319. 20

AYLETT, R. et al. Training in social signals with a robot for adults with an asc. 2018. 34

BEGUM, M. et al. Measuring the efficacy of robots in autism therapy: How informative are standard hri metrics'. In: *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*. [S.l.: s.n.], 2015. p. 335–342. 20, 28, 147

BILLARD, A. et al. Building robota, a mini-humanoid robot for the rehabilitation of children with autism. *Assistive Technology*, Taylor & Francis, v. 19, n. 1, p. 37–49, 2007. 34

BRADSKI, G.; KAEHLER, A. *Learning OpenCV: Computer Vision with the OpenCV Library*. [S.l.]: O'Reilly Media, 2008. 46, 47

BRISBEN, A. et al. The cosmobot system: Evaluating its usability in therapy sessions with children diagnosed with cerebral palsy. *Retrieved on*, v. 3, n. 25, p. 13, 2005. 32

BROOKE, J. Sus: a retrospective. *Journal of usability studies*, Usability Professionals' Association Bloomingdale, IL, v. 8, n. 2, p. 29–40, 2013. 82, 91

CASPERSON, M. K. *An Analysis on the Effects of Melodic Based Communication Therapy on Verbal Behavior in Children with Autism Spectrum Disorder*. Tese (Doutorado) — Nova Southeastern University, 2023. 19

CASSIDY S.; STENGER, B. V. D. L. Y. K. A. R. W. V. B.-C. S. C. R. *BeeSmart: A Gesture-Based Videogame to Support Literacy and Eye-Hand Coordination of Children with Down Syndrome.* [S.l.]: Computer Vision and Image Understanding., 2015. v. 148, 193-200. https://doi.org/10.1016/j.cviu.2015.08.011. 45

CHIAROTTI, F.; VENEROSI, A. Epidemiology of autism spectrum disorders: a review of worldwide prevalence estimates since 2014. *Brain sciences*, Multidisciplinary Digital Publishing Institute, v. 10, n. 5, p. 274, 2020. 26

CHO, H.-J.; LEE, B.-H. Effect of functional progressive resistance exercise on lower extremity structure, muscle tone, dynamic balance and functional ability in children with spastic cerebral palsy. *Children*, v. 7, n. 8, 2020. ISSN 2227-9067. Disponível em: <https://www.mdpi.com/2227-9067/7/8/85>. 65

CHO, S.-J.; AHN, D. H. Socially assistive robotics in autism spectrum disorder. *Hanyang Medical Reviews*, Hanyang University School of Medicine, v. 36, n. 1, p. 17–26, 2016. 19, 21, 22, 29, 30, 35

CLABAUGH, C. et al. Long-term personalization of an in-home socially assistive robot for children with autism spectrum disorders. *Frontiers in Robotics and AI*, Frontiers Media SA, v. 6, p. 110, 2019. 21, 22, 30, 48

COOPER, J. O. et al. Applied behavior analysis. Pearson/Merrill-Prentice Hall Upper Saddle River, NJ, 2007. 26, 27

COSTA, S. et al. Using a humanoid robot to elicit body awareness and appropriate physical interaction in children with autism. *International journal of social robotics*, Springer, v. 7, p. 265–278, 2015. 90

D'AMICO, M.; LALONDE, C. The effectiveness of art therapy for teaching social skills to children with autism spectrum disorder. *Art Therapy*, Taylor & Francis, v. 34, n. 4, p. 176–182, 2017. 78

DAUTENHAHN, K. et al. Kaspar–a minimally expressive humanoid robot for human–robot interaction research. *Applied Bionics and Biomechanics*, IOS Press, v. 6, n. 3-4, p. 369–397, 2009. 32

DICHEVA, D. et al. Gamification in education: A systematic mapping study. *Journal of educational technology & society*, JSTOR, v. 18, n. 3, p. 75–88, 2015. 44

DICKSTEIN-FISCHER, L.; FISCHER, G. S. Combining psychological and engineering approaches to utilizing social robots with children with autism. In: IEEE. *2014 36th annual international conference of the IEEE engineering in medicine and biology society*. [S.l.], 2014. p. 792–795. 19, 21, 27, 33

DICKSTEIN-FISCHER, L. A. et al. Socially assistive robots: current status and future prospects for autism interventions. *Innovation and Entrepreneurship in Health*, Dove Press, v. 5, p. 15–25, 2018. 19, 21, 27, 28, 29, 30, 35, 36

DOUNAVI, K. Applied behavior analysis treatment of autism spectrum disorder: Practice guidelines for healthcare funders and managers (translation to greek). 2017. 27

DUNST, C. J. et al. Influences of a socially interactive robot on the affective behavior of young children with disabilities. social robots research reports, number 3. *Orelena Hawks Puckett Institute*, ERIC, 2013. 32

DUQUETTE, A.; MICHAUD, F.; MERCIER, H. Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots*, Springer, v. 24, n. 2, p. 147–157, 2008. 32

FARABET, C. et al. Learning hierarchical features for scene labeling. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, v. 35, n. 8, p. 1915–1929, 2013. 47

FEIL-SEIFER, D.; MATARIĆ, M. J. Socially assistive robotics. *IEEE Robotics & Automation Magazine*, IEEE, v. 18, n. 1, p. 24–31, 2011. 29, 35

FENG, Y. et al. A control architecture of robot-assisted intervention for children with autism spectrum disorders. *Journal of Robotics*, Hindawi, v. 2018, 2018. 20, 29, 147

FONSECA, V. d. *INSTRUMENTO DE AVALIAÇÃO. Bateria Psicomotora (BPM). Manual de Observação Psicomotora, Significação Psiconeurológica dos Fatores Psicomotores*. Porto Alegre: Artes Médicas, 1995. 371 p. 82, 148

FREITAS, E. V. S. et al. Memo the game: Serius game for development of memorization in children with autistic spectrum disorder. In: *XXVIII Congresso Brasileiro de Engenharia Biomédica*. Florianópolis, SC: [s.n.], 2022. 50

FREITAS, E. V. S. et al. Raining food: Serious game for nutrition education therapies in children with disabilities. In: *XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad*. São Carlos, SP, Brazil: [s.n.], 2023. 71

FREITAS, H. et al. Using a humanoid robot as the promoter of the interaction with children in the context of educational games. *International Journal of Mechatronics and Applied Mechanics*, Editura Cefin, v. 1, 2017. 31

GAIATO, M. *SOS Autismo: Guia completo para entender o Transtorno do Espectro Autista*. [S.l.]: nVersos, 2018. 19, 27, 28

GOULART, C. *Uma contribuição ao estudo de sinais de EEG para avaliar estados emocionais e mentais de crianças com autismo na interação com robô móvel. 2018*. [S.l.]: Dissertação (Mestrado em Biotecnologia)–Programa de Pós-graduação em . . . , 2015. 90

HAAS, J. K. A history of the unity game engine. Worcester Polytechnic Institute, 2014. 47

HANH, T. N. *Planting seeds: Practicing mindfulness with children*. [S.l.]: Parallax press, 2007. 78

HOCINE, N.; GOUAÏCH, A.; LORETO, I. D. Dynamic difficulty adaptation in therapeutic serious games after stroke. *ICBL 2011*, p. 84, 2011. 45

HODGES, H.; FEALKO, C.; SOARES, N. Autism spectrum disorder: definition, epidemiology, causes, and clinical evaluation. *Translational pediatrics*, AME Publications, v. 9, n. Suppl 1, p. S55, 2020. 25

HOF, M. van't et al. Age at autism spectrum disorder diagnosis: A systematic review and meta-analysis from 2012 to 2019. *Autism*, SAGE Publications Sage UK: London, England, v. 25, n. 4, p. 862–873, 2021. 26

HSU, H.; LACHENBRUCH, P. A. Paired t test. *Wiley StatsRef: statistics reference online*, Wiley Online Library, 2014. 89

HU, G.; TAY, W. P.; WEN, Y. Cloud robotics: architecture, challenges and applications. *IEEE Network*, v. 26, n. 3, p. 21–28, 2012. 39

HYDE, K. K. et al. Applications of supervised machine learning in autism spectrum disorder research: a review. *Review Journal of Autism and Developmental Disorders*, Springer, v. 6, n. 2, p. 128–146, 2019. 19, 21, 22

HYMAN, S. L. et al. Identification, evaluation, and management of children with autism spectrum disorder. *Pediatrics*, American Academy of Pediatrics, v. 145, n. 1, 2020. 19, 22, 25, 26, 67

IBGE. *Perfil das Crianças Brasileiras*. 2018. Acesso em: 10/07/2023. Disponível em: <https://educa.ibge.gov.br/criancas/brasil/2697-ie-ibge-educa/jovens/materias-especiais/20786-perfil-das-criancas-brasileiras.html>. 25

INBAR, E. *The Robot Enhancing How Children with Autism Learn*. Dell, 2018. Disponível em: <https://www.dell.com/en-us/perspectives/the-robot-enhancing-how-children-with-autism-learn/>. 21

INBAR, E. *Online training for the Nao Robot*. RobotLAB, 2023. Disponível em: <https://www.robotlab.com/store/nao-training-professional-development>. 21

ISBELL, C. *Mighty Fine Motor Fun: Fine Motor Activities for Young Children*. [S.l.]: ReadHowYouWant. com, 2010. 77

JÁCOME, J. et al. Parallax engine: Head controlled motion parallax using notebooks' rgb camera. In: *Symposium on Virtual and Augmented Reality*. [S.l.: s.n.], 2021. p. 137–146. 47

KANKAANRANTA M.H.; NEITTAANMäKI, P. *Design and Use of Serious Games*. [S.l.]: Springer, 2008. Volume 37. 44

KARAR, A. et al. Pepper humanoid robot as a service robot: a customer approach. In: IEEE. *2019 3rd International Conference on Bio-engineering for Smart Technologies (BioSMART)*. [S.l.], 2019. p. 1–4. 33

KATES-MCELRATH, K.; AXELROD, S. Behavioral intervention for autism: A distinction between two behavior analytic approaches. *The Behavior Analyst Today*, Joseph D. Cautilli, v. 7, n. 2, p. 242, 2006. 20

KATO, S. et al. Development of a communication robot ifbot. In: IEEE. *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA'04. 2004*. [S.l.], 2004. v. 1, p. 697–702. 33

KHODATARS, M. et al. Deep learning for neuroimaging-based diagnosis and rehabilitation of autism spectrum disorder: a review. *Computers in Biology and Medicine*, Elsevier, v. 139, p. 104949, 2021. 21

KOEGEL, R. L. et al. *Pivotal response treatment for autism spectrum disorders*. [S.l.]: Paul H. Brookes Publishing Company, 2019. 20, 28

KOZIMA, H.; MICHALOWSKI, M. P.; NAKAGAWA, C. Keepon. *International Journal of social robotics*, Springer, v. 1, n. 1, p. 3–18, 2009. 31

KRASNY-PACINI, A. et al. Goal attainment scaling in rehabilitation: a literature-based update. *Annals of physical and rehabilitation medicine*, Elsevier, v. 56, n. 3, p. 212–230, 2013. 82, 88, 89

KRISTAN, D. et al. Creating competitive opponents for serious games through dynamic difficulty adjustment. *Information*, MDPI, v. 11, n. 3, p. 156, 2020. 45, 46

KRITHIGA, R. Socially assistive robot for children with autism spectrum disorder. In: IEEE. *2019 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE)*. [S.l.], 2019. p. 1–4. 26, 30

KURTZ, E. A. *Simple Low-Cost Games and Activities for Sensorimotor Learning: A Sourcebook of Ideas for Young Children Including Those with Autism, ADHD, Sensory Processing Disorder, and Other Learning Differences*. [S.l.]: Jessica Kingsley Publishers, 2014. 78

LEI, J.; VENTOLA, P. Pivotal response treatment for autism spectrum disorder: current perspectives. *Neuropsychiatric disease and treatment*, Taylor & Francis, p. 1613–1626, 2017. 20

LEWIS, J. R.; SAURO, J. The factor structure of the system usability scale. In: SPRINGER. *International conference on human centered design*. [S.l.], 2009. p. 94–103. 82

LI, J. et al. Using body sensor network to measure the effect of rehabilitation therapy on improvement of lower limb motor function in children with spastic diplegia. *IEEE Transactions on Instrumentation and Measurement*, v. 69, n. 11, p. 9215–9227, 2020. 65

LI, Q. et al. Prevalence of autism spectrum disorder among children and adolescents in the united states from 2019 to 2020. *JAMA pediatrics*, American Medical Association, v. 176, n. 9, p. 943–945, 2022. 25

LICARI, M. K. et al. Prevalence of motor difficulties in autism spectrum disorder: Analysis of a population-based cohort. *Autism Research*, Wiley Online Library, v. 13, n. 2, p. 298–306, 2020. 22, 26

LOUIE, W.-Y. G. et al. A study on an applied behavior analysis-based robot-mediated listening comprehension intervention for asd. *Paladyn, Journal of Behavioral Robotics*, De Gruyter Open Access, v. 12, n. 1, p. 31–46, 2021. 27, 28, 29

LUGARESI, C. et al. *MediaPipe: A Framework for Building Perception Pipelines*. arXiv, 2019. Disponível em: <https://arxiv.org/abs/1906.08172>. 40, 46

MACIEL, M. C. R. et al. Terapia assistida por robô para o desenvolvimento de habilidades de desempenho e otimização do desempenho ocupacional de crianças com transtorno do espectro autista. In: *XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidade*. São Carlos, SP, Brazil: [s.n.], 2023. 74

MAENNER, M. J. et al. Prevalence and characteristics of autism spectrum disorder among children aged 8 years — autism and developmental disabilities monitoring network, 11 sites, united states, 2018. *MMWR Surveill Summ*, v. 70, n. SS-11, p. 1–16, 2021. Disponível em: <http://dx.doi.org/10.15585/mmwr.ss7011a1>. 25

MANCINI, M. C. et al. New version of the pediatric evaluation of disability inventory (pedi-cat): translation, cultural adaptation to brazil and analyses of psychometric properties. *Brazilian Journal of Physical Therapy*, SciELO Brasil, v. 20, p. 561–570, 2016. 87

MARTINEZ-MARTIN, E.; ESCALONA, F.; CAZORLA, M. Socially assistive robots for older adults and people with autism: An overview. *Electronics*, MDPI, v. 9, n. 2, p. 367, 2020. 19, 27, 29, 30, 35

MATSON, J. L. et al. Applied behavior analysis in autism spectrum disorders: Recent developments, strengths, and pitfalls. *Research in Autism Spectrum Disorders*, Elsevier, v. 6, n. 1, p. 144–150, 2012. 19, 25, 26, 27, 29, 68

MOERMAN, C. J.; JANSENS, R. M. Using social robot pleo to enhance the well-being of hospitalised children. *Journal of Child Health Care*, SAGE Publications Sage UK: London, England, v. 25, n. 3, p. 412–426, 2021. 31

MONTIEL, J. M.; SEABRA, A. G. Teste de atenção por cancelamento. *Avaliação neuropsicológica cognitiva: Atenção e funções executivas*, Memnon São Paulo, v. 1, p. 57–66, 2012. 82

MOUNZER, W. et al. A follow-up study of early intensive behavioral intervention program for children with autism in syria. *Scientific Reports*, Nature Publishing Group UK London, v. 13, n. 1, p. 70, 2023. 20

NEGRI, Y. R. et al. Proposal of serious games for a socially assistive robot based on eye contact and visual attention of children with autism spectrum disorder. In: *XXVIII Congresso Brasileiro de Engenharia Biomédica*. Florianópolis, SC: [s.n.], 2022. 58

NOOR, H. A. M.; SHAHBODIN, F.; PEE, N. C. Serious game for autism children: review of literature. *International Journal of Psychological and Behavioral Sciences*, v. 6, n. 4, p. 554–559, 2012. 44

OLIVEIRA, J. da S. et al. Ibm watson application as faq assistant about moodle. In: IEEE. *2019 IEEE Frontiers in Education Conference (FIE)*. [S.l.], 2019. p. 1–8. 38, 39

OMAR, K. S. et al. A machine learning approach to predict autism spectrum disorder. In: IEEE. *2019 International conference on electrical, computer and communication engineering (ECCE)*. [S.l.], 2019. p. 1–6. 25

PAKKAR, R. et al. Designing a socially assistive robot for long-term in-home use for children with autism spectrum disorders. In: IEEE. *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. [S.l.], 2019. p. 1–7. 30

PANCERI, J. A. C. et al. A new socially assistive robot with integrated serious games for therapies with children with autism spectrum disorder and down syndrome: A pilot study. *Sensors*, v. 21, n. 24, 2021. ISSN 1424-8220. Disponível em: <https://www.mdpi.com/1424-8220/21/24/8414>. 36, 41, 65

PANCERI, J. A. C. et al. Proposal of a new socially assistive robot with embedded serious games for therapy with children with autistic spectrum disorder and down syndrome. In: SPRINGER. *Brazilian Congress on Biomedical Engineering*. [S.l.], 2022. p. 1399–1405. 36

PANCERI J.A.C.; FREITAS, E. B.-F. T. *Proposal of a New Socially Assistive Robot with Embedded Serious Games for Therapy with Children with Autistic Spectrum Disorder and Down Syndrome*. [S.l.]: CBEB: Vitoria, Brasil,, 2020. v. 1865–1870. 44

PANCERI, R. C. et al. Crosskids: The serious game developed for motor deficit therapies in children using the social robot maria t21. In: *XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad*. São Carlos, SP, Brazil: [s.n.], 2023. 66

PENG, C. et al. A visuo-haptic attention training game with dynamic adjustment of difficulty. *IEEE Access*, IEEE, v. 7, p. 68878–68891, 2019. 45, 46

PFAU, J.; SMEDDINCK, J. D.; MALAKA, R. Enemy within: Long-term motivation effects of deep player behavior models for dynamic difficulty adjustment. In: *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. [S.l.: s.n.], 2020. p. 1–10. 45, 46

PIERCE, K. et al. Evaluation of the diagnostic stability of the early autism spectrum disorder phenotype in the general population starting at 12 months. *JAMA pediatrics*, American Medical Association, v. 173, n. 6, p. 578–587, 2019. 19, 25, 26

PIERO, G. P. D. et al. Implementation of dynamic faces based on proxemics for robot-asd children interaction. 2019. 34

PROCTOR, R. W. Playing the simon game: Use of the simon task for investigating human information processing. *Acta Psychologica*, Elsevier, v. 136, n. 2, p. 182–188, 2011. 48

QIAN, M.; CLARK, K. R. Game-based learning and 21st century skills: A review of recent research. *Computers in human behavior*, Elsevier, v. 63, p. 50–58, 2016. 44, 45

QIU, S. et al. Prevalence of autism spectrum disorder in asia: A systematic review and meta-analysis. *Psychiatry research*, Elsevier, v. 284, p. 112679, 2020. 25, 26

QUIGLEY M.; CONLEY, K. G.-B. F. J. F. T. L. J. W. R. N. A. *ROS: An open-source robot operating system.* [S.l.]: ICRA Workshop on Open Source Software., 2009. v.3. 40

RAJ, S.; MASOOD, S. Analysis and detection of autism spectrum disorder using machine learning techniques. *Procedia Computer Science*, Elsevier, v. 167, p. 994–1004, 2020. 25

RALSTON, K. et al. A voice interactive multilingual student support system using ibm watson. In: IEEE. *2019 18th IEEE International Conference On Machine Learning And Applications (ICMLA)*. [S.l.], 2019. p. 1924–1929. 38, 39

ROGGE, N.; JANSSEN, J. The economic costs of autism spectrum disorder: A literature review. *Journal of Autism and Developmental Disorders*, Springer, v. 49, n. 7, p. 2873–2900, 2019. 19, 21, 25

SALVADOR, M. et al. Development of an aba autism intervention delivered by a humanoid robot. In: SPRINGER. *International Conference on Social Robotics*. [S.l.], 2016. p. 551–560. 20, 29, 147

SANTOS C.; SOUZA J.; VALTUIR; LANZA, F. L. A. J. B. M. I. *Serious games in virtual environments for health teaching and learning.* [S.l.: s.n.], 2017. v.18. 702-709. 10.15253/2175-6783.2017000500019. 20

SCASSELLATI, B. et al. Robots for use in autism research. *Annual review of biomedical engineering*, Annual Reviews, v. 14, p. 275–294, 2012. 90

SCHREIDER, S. L. et al. Intervenção psicomotora por meio de jogos sérios em crianças e adolescentes com síndrome de down utilizando robô terapêutico. In: *XII Congreso Iberoamericano de Tecnologías de Apoyo a la Discapacidad*. São Carlos, SP, Brazil: [s.n.], 2023. 66

SCOTT, W. A. Cognitive complexity and cognitive flexibility. *Sociometry*, JSTOR, p. 405–414, 1962. 92

SHAFIE, A. binti. Collage activities to improve fine motor skills mastery in students with learning disabilities. *Best Practices in Disability-Inclusive Education*, v. 1, 2022. 76, 143

SHAMSUDDIN, S. et al. Humanoid robot nao: Review of control and motion exploration. In: IEEE. *2011 IEEE international conference on Control System, Computing and Engineering*. [S.l.], 2011. p. 511–516. 31

SHAMSUDDIN, S. et al. Robot-assisted learning for communication-care in autism intervention. In: IEEE. *2015 IEEE International Conference on Rehabilitation Robotics (ICORR)*. [S.l.], 2015. p. 822–827. 19, 25, 26, 27, 29, 30

SHOHIEB, S. M.; DOENYAS, C.; ELHADY, A. M. Dynamic difficulty adjustment technique-based mobile vocabulary learning game for children with autism spectrum disorder. *Entertainment Computing*, Elsevier, v. 42, p. 100495, 2022. 45

SILVA, G. M. et al. Interventions with serious games and entertainment games in autism spectrum disorder: a systematic review. *Developmental neuropsychology*, Taylor & Francis, v. 46, n. 7, p. 463–485, 2021. 44, 45

SMITH, T.; EIKESETH, S. O. ivar lovaas: Pioneer of applied behavior analysis and intervention for children with autism. *Journal of autism and developmental disorders*, Springer, v. 41, n. 3, p. 375–378, 2011. 26, 28

SONGBIRD. *How much does ABA therapy cost? Overall costs to expect: Autism Resources*. Dell, 2022. Disponível em: <https://www.songbirdcare.com/articles/how-much-does-aba-therapy-cost>. 19, 21, 27

STEINER, C. et al. Evaluation of serious games: A holistic approach. In: IATED ACADEMY. *ICERI2015: 8th annual International Conference of Education, Research and Innovation*. [S.l.], 2015. p. 4334–4342. 20

STRICKLAND, E. Ibm watson, heal thyself: How ibm overpromised and underdelivered on ai health care. *IEEE Spectrum*, IEEE, v. 56, n. 4, p. 24–31, 2019. 39

TREVISAN, B.; SEABRA, A. Teste de trilhas para pré-escolares. *Avaliação neuropsicológica cognitiva: Atenção e funções executivas*, Memnon São Paulo, SP, v. 1, p. 92–100, 2012. 82

TURNER-STOKES, L. Goal attainment scaling (gas) in rehabilitation: a practical guide. *Clinical rehabilitation*, SAGE Publications Sage UK: London, England, v. 23, n. 4, p. 362–370, 2009. 82, 88

VALENCIA, N. et al. Serious game for post-stroke upper limb rehabilitation. In: SPRINGER. *Converging Clinical and Engineering Research on Neurorehabilitation II: Proceedings of the 3rd International Conference on NeuroRehabilitation (ICNR2016), October 18-21, 2016, Segovia, Spain*. [S.l.], 2017. p. 1445–1450. 44

VANG, C. The impact of dynamic difficulty adjustment on player experience in video games. *Scholarly Horizons: University of Minnesota, Morris Undergraduate Journal*, v. 9, n. 1, p. 7, 2022. 45

WADA, K. et al. Development and preliminary evaluation of a caregiver's manual for robot therapy using the therapeutic seal robot paro. In: IEEE. *19th International Symposium in Robot and Human Interactive Communication*. [S.l.], 2010. p. 533–538. 34

WAN, J. et al. Cloud robotics: Current status and open issues. *IEEE Access*, v. 4, p. 2797–2807, 2016. 39

WARREN, Z. et al. Brief report: development of a robotic intervention platform for young children with asd. *Journal of autism and developmental disorders*, Springer, v. 45, n. 12, p. 3870–3876, 2015. 20, 147

WATANABE, K.; YONEDA, Y. The world's smallest biped humanoid robot "i-sobot". In: IEEE. *2009 IEEE Workshop on Advanced Robotics and its Social Impacts*. [S.l.], 2009. p. 51–53. 33

ZHANG, K. et al. Effects of drawing therapy on pediatric oncology patients: a systematic review. *Cancer Nursing*, LWW, v. 45, n. 2, p. E397–E406, 2022. 75, 142