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PAPER

Cognitive Serious Games Dynamically Modulated as a Therapeutic Tool for Applied Behavior Analysis Therapy in Children with Autism Spectrum Disorder

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ABSTRACT

This study introduces three dynamically modulated serious cognitive games as a therapeutic tool for Applied Behavior Analysis (ABA) in children with Autism Spectrum Disorder (ASD), employing the Socially Assistive Robot (SAR) MARIA T21 (Mobile Autonomous Robot for Interaction with Autistics and Trisomy 21). Developed in Unity 3D, the games are modulated based on performance and eye attention levels (measured a camera). The child-robot interaction protocol involved 18 children diagnosed with ASD, aged 5 to 9, conducted in a psychotherapy room. The results recorded by onboard sensors demonstrate the efficacy of the SAR MARIA T21 as an ABA therapeutic tool, with the dynamically adjusting difficulty levels to enhance engagement and sustained attention within the learning zone recommended by ABA literature.

KEYWORDS

serious games, autism spectrum disorder, dynamic difficult adjustment

1 INTRODUCTION

Autism Spectrum Disorder (ASD) poses a significant societal challenge, given its increasing prevalence and the lifelong support required across education, healthcare, and community services, leading to substantial financial burdens on individuals, families, public services, and society as a whole [1]. Emergence of Socially Assistive Robots (SAR) offers a promising avenue to enhance ASD interventions, expanding assessment and therapeutic possibilities for children [2]. Robotic systems provide personalized, continuous sessions, enhancing screening, diagnosis, and monitoring processes while collecting valuable interaction data for therapists [3].

While SAR has shown promise in traditional therapies based on Applied Behavior Analysis (ABA), particularly Discrete Trial Training (DTT), its application in Pivotal

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Response Training (PRT), a method emphasizing child motivation and joy during learning, remains unexplored [4, 5]. This gap is attributed to the complexities of PRT, which requires adaptable protocols based on diverse variables such as attention and cognitive levels [4].

Accessing ASD therapy is hindered by limited professional resources, administrative burdens, therapist burnout, and high costs [1, 6]. Additionally, effective diagnostics and progress monitoring lack reliable methods, prompting the need for objective assessments – a gap that SARs aim to address [2]. However, customized therapies, crucial for children with ASD, remain resource intensive, creating an opportunity for SAR supported interventions [7].

This study introduces an innovative approach using SGs assisted by MARIA T21 for ABA-based therapy. Tailored SGs dynamically adjust difficulty levels based on individual learning patterns, focusing on cognitive skill enhancements, and aligning with ABA principles encompassing both DTT and PRT methodologies.

2 APPLIED BEHAVIOR ANALYSIS

ABA, also known as the Lovaas Model, stands out as the most widely used evidence based method for addressing social and communication deficits, and reducing challenging behaviors like stereotypes [8, 9]. ABA encompasses teaching social skills, play skills, group instruction, academic behaviors, and Activities of Daily Living (ADLs). In the United States, Individualized Education Programs (IEPs) mandate ABA for children with behavior problems leading to alternative educational placements, yet the shortage of qualified ABA analysts in many areas hampers timely service delivery [10]. Cost of intensive ABA services ranges from US$46,000 to US$100,000 per year, posing financial challenges for families [6, 11].

In Brazil, ABA therapy is covered by the national health system as the exclusive therapeutic intervention methodology for ASD. Worldwide, ABA is well-known for aiding children with special needs, particularly those with ASD and intellectual delay [10]. ABA utilizes a behavior modification approach, breaking down target behaviors into simple, sequential, and repetitive tasks, with performance measured and analyzed during therapy. Plasticity of the human brain allows children with ASD to learn new skills and unlearn inappropriate behaviors through ABA [9, 3]. The extensive history of ABA research has yielded more promising results than any other method to date [12].

Given the unique deficits of each individual, ABA clinical practice involves personalized procedures, including the assessment of deficits and excesses, implementation of a customized intervention plan, and continuous frequent reassessment of the intervention. ABA instruction methods vary, with Verbal Behavior Intervention (VBI) focusing on verbal skills, and Early Intensive Behavioral Intervention (EIBI) typically applied to children under three years old. Other types include DTT and PRT, also known as naturalistic ABA [4].

3 SERIOUS GAMES AND DYNAMIC DIFFICULTY ADJUSTMENT

SGs are crafted with distinct purposes beyond entertainment, serving areas like training, education, social awareness, and business simulation [13]. These games leverage interactive technology and game elements such as characters, narratives, rewards, and challenges to effectively achieve their goals in an engaging manner [14].

Moreover, SGs have been integrated into therapeutic contexts, providing patients with a controlled environment to explore concerns and develop coping skills for psychological and mental health disorders [15]. In the therapy of ASD, SGs have demonstrated success as tools for teaching and enhancing social and communication skills while addressing problematic behaviors [16]. Dynamic Difficulty Adjustment (DDA) stands out as a game design technique dynamically tailoring game difficulty in real-time based on the player's skills and performance. Utilizing machine learning algorithms, DDA ensures a customizable challenge level, fostering engagement and learning progress while preventing excessive frustration [17].

DDA continuously monitors a player's performance, allowing dynamic ad justments game difficulty. For instance, when a player easily achieves success, the difficulty increases, and conversely, if the player struggles, the difficulty decreases. This adaptive approach enables continuous player progress while maintaining an appropriate challenge level. Nevertheless, careful calibration of difficulty is crucial to prevent extreme fluctuations that might negatively impact the player's experience [18].

4 MATERIALS AND METHODS

4.1 MARIA T21

The SAR MARIA T21 was meticulously developed at the Federal University of Espirito Santo (UFES/Brazil) by a multidisciplinary team specialized in robots designed for interaction with children diagnosed with ASD and Trisomy 21 (T21). This innovative robot serves a dual purpose, contributing to both the learning and training of basic ADLs, as well as the dynamic evaluation of the children's characteristics during exercises and therapeutic activities [19]. Refer to Figure 1 for an illustration of the robot MARIA T21.

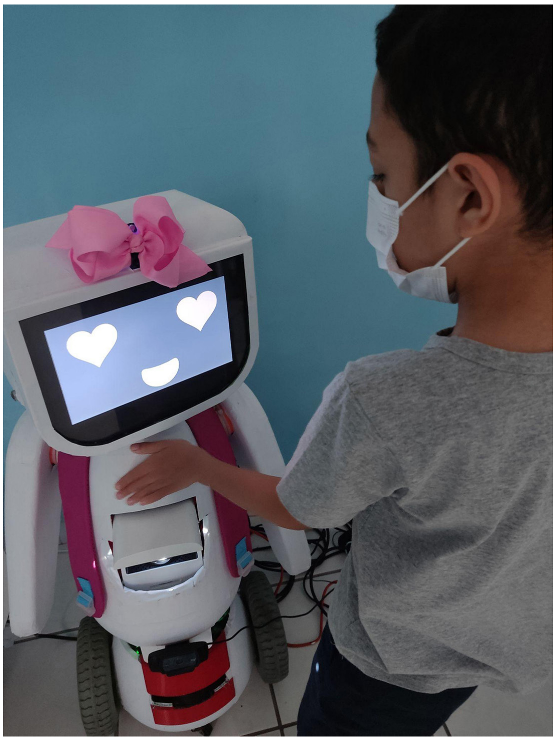

Fig. 1. Robot MARIA T21 developed at UFES/Brazil

Equipped with an integrated LG HF85LA video projector, MARIA T21 features 1500 Lumens, Full-HD resolution, and laser technology. This projector seamlessly embedded within the robot's structure enables the projection of SGs onto the floor or table, fostering engagement with the child. During SG projections, the robot actively guides the child, offering encouragement through pre-recorded verbal testimonials and facilitating dynamic responses tailored to the child's inquiries. The computer vision system, powered by a Logitech C920 PRO camera, captures frontal images of the child's movements, playing a key role in identifying and interpreting body movements during therapy.

4.2 Software Requirements

MediaPipe, a dynamic software framework used here, excels in real-time media processing with modular pipelines. Adaptable to Android, iOS, Linux, and Raspberry Pi, it integrates with TensorFlow and Python, enhancing adaptability. Coupled with Unity, it facilitates gesture-based interactions in SGs [20]. OpenCV, an open-source library, supports C++, Python, and JaCognitive Serious Gamesva, excelling in image processing, computer vision, and machine learning [21]. Unity 3D, a robust game development tool, supports 2D and 3D creations, providing user-friendliness, advanced graphics, and multi-language support, making it ideal for SGs development [22].

In addition to the SAR's embedded and external technology, including a sensing mat and camera systems, a Dell Gamer Notebook G3-3500-A40, used for communication, was essential. Connectivity was facilitated by a dual-band Archer C6 wireless router.

5 MATERIALS AND METHODS

In this study, three 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.

5.1 Memô

The game Memô comprises three colored squares – yellow, blue, and red – projected onto a table using the MARIA T21 technology. These squares emit sounds upon flashing (Figure 2 to the left of the home screen and to the right of the screen in phase 2). The child must replicate the presented sequence: one of the squares is randomly highlighted for two seconds and emits a musical note. As the difficulty increases, 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.

Fig. 2. SG Memô

Memô utilizes the MARIA T21's top camera and the MediaPipe technology and focus of attention, enabling efficient control.

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.

The SG Memô 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 seconds 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 his/her 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 the actual level. In relation to the score, it 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.

5.2 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. If a monster achieves the treasure, the game is over (or the player loses one life).

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 3 displays the game interface.

Fig. 3. SG Goblin Gold

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

There are four types of enemy from A to D, with different velocities and strengths, represented by baseScore (from 2 to 5) that described difficult offered to the player to defeat them, each one presenting a damage (varying from 1 to 4) representing the lives lost when they arrive to the treasure.

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.

The monitoring of performance and DDA is accomplished using global variables and their associated contexts.

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 – Global base multiplier for enemy health). Upon achieving this stage for the third consecutive time, a 20% increase is also applied to the base enemy speed multiplier (modulSpeedMult – Global base multiplier for enemy speed). Similarly, when a child encounters the game over screen due to failing a level (losing all his/her 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.

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.

5.3 MARIA's Homework

The SG MARIA's Homework utilizes the MARIA T21 robot 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 (Figure 4). 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 their abilities and prior knowledge.

Fig. 4. SG MARIA's Homework

The MARIA's Homework game focuses on crucial assessment areas essential for the holistic development of children with ASD. These areas encompass safety and self-care, mathematics, world knowledge, logic and logical reasoning, shape and figure recognition, and recognition of emotions and feelings. Each thematic area consists of 36 questions, with a progressive difficulty level. The game employs an interactive platform, allowing children to engage with questions, express emotions, and improve their cognitive, social, and emotional skills. The facilitators have the flexibility to adapt the game to individual reading abilities, with the robot providing question statements and displaying answer alternatives for recognition. A comprehensive report is generated at the end, detailing the child's performance, facilitating further guidance and evaluation.

This game aims to deliver a range of benefits for children with ASD, therapists, and family members alike. For children, it focuses on enhancing engagement, motivation, and cognitive skills such as logical reasoning, problem-solving, memory, and critical thinking.

Therapists can integrate the game MARIA's Homework into educational interventions, utilizing it as a complementary tool for teaching and reinforcing academic and social skills. Parents can actively monitor their children's progress in the game, identifying areas that may need additional support and providing positive feedback.

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.

6 MATERIALS AND METHODS

Eighteen children diagnosed with ASD in mild to moderate 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 Association of Parents and Friends of Exceptional People (APAE) in Vitoria, state of 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 following study's inclusion criteria: diagnosis according to Diagnostic and Statistical Manual of Mental Disorders (DSM-5) for ASD; age between 5 and 9 years old; and both genders.

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 1 presents the profile of the participants.

Table 1. Profile of participants in the advanced experiment

Participant	Sex	Age	Level
K1	Male	7	Moderate
K2	Female	8	Mild
K3	Male	9	Mild
K4	Male	7	Moderate/Severe
K5	Female	6	Mild
K6	Male	6	Moderate
K7	Male	8	Moderate
K8	Male	7	Moderate
K9	Female	7	Moderate
K10	Male	6	Moderate
K11	Male	7	Mild/Moderate
K12	Male	7	Mild
K13	Male	6	Mild/Moderate
K14	Male	6	Mild/Moderate
K15	Male	7	Moderate/Severe
K16	Male	7	Mild/High Skills
K17	Male	7	Mild
K18	Male	9	Moderate/Severe

7 RESULTS

The SG Memô 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, but always encouraged autonomy in decision-making and the use of the robot as the primary facilitator. The weekly time spent on this game was at least 15 minutes per child participant. Tables 2 and 3 show the number of weekly messages sent by the robot to each child in weeks with modulation, to maintain and/or regain the child's attention during the display of the color sequence.

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.

Table 2. Number of attention calls (Part 1)

Week/Participant	K1	K2	K3	K4	K5	K6	K7	K8	K9
5	4	4	3	8	3	5	4	12	7
6	6	4	3	9	1	6	3	10	7
7	5	5	3	7	2	5	4	11	5
8	4	4	2	6	2	5	4	10	6

Table 3. Number of attention calls (Part 2)

Week/Participant	K10	K11	K12	K13	K14	K15	K16	K17	K18
5	5	8	5	3	2	15	4	4	11
6	5	7	5	3	2	12	3	5	9
7	5	7	9	4	1	8	1	5	9
8	5	9	8	3	2	10	1	3	8

The SG MARIA's Homework was applied for 4 weeks to 8 participants (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. Tables 4 and 5 show the total number of correct answers in each assessment area over the 4 weeks of application.

Table 4. Safety and Self-Care, Mathematics and World Knowledge for four weeks (W1 to W4)

Child/Week	Safety and Self-Care				Mathematics				World Knowledge			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
K1	3	3	4	4	1	1	2	2	3	3	3	4
K4	1	2	1	2	1	1	2	1	3	0	1	2
K9	4	5	5	5	2	2	3	3	4	4	3	4
K11	6	5	6	6	3	3	3	4	6	5	4	5
K13	5	4	5	6	4	5	5	5	3	4	3	4
K16	5	5	5	6	5	6	6	6	4	5	6	5
K17	4	4	4	5	6	6	5	6	5	5	6	6
K18	0	0	1	1	0	1	0	0	0	0	1	0

Table 5. Logic and Logic Reasoning (L&LR), Knowledge of Shapes and Figures (KS&F) and Recognizing of Emotions, and Feelings (RE&F) for four weeks (W1 to W4)

Child/Week	L&LR				KS&F				RE&F			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
K1	0	0	0	0	3	3	4	4	6	5	6	5
K4	0	0	0	0	2	3	1	3	3	2	2	3
K9	0	1	1	1	5	4	5	6	6	6	5	6
K11	2	2	2	3	5	5	6	5	4	6	6	6
K13	3	3	3	3	4	4	5	5	5	5	6	6
K16	4	6	5	5	6	6	6	6	5	6	6	6
K17	5	4	5	5	6	6	6	6	6	6	5	6
K18	0	0	0	0	2	1	1	1	1	0	0	0

Results, as illustrated in Tables 4 and 5, demonstrate the progression of correct answers across various assessment domains throughout the intervention duration. Notably, participants exhibited improvements in safety and self-care, mathematics, world knowledge, logic reasoning, knowledge of shapes and figures, as well as recognizing emotions and feelings. These findings suggest the effectiveness of tailored interventions in addressing individual learning needs and fostering holistic skill development among young learners. The SG Goblin Gold was 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.

The individual performance of the participants K1 and K16 (the volunteers with the least and most expressive results, respectively) in the first and last data collections for this SG is presented in Figure 5. The values in the vertical columns representing the performance per level 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.

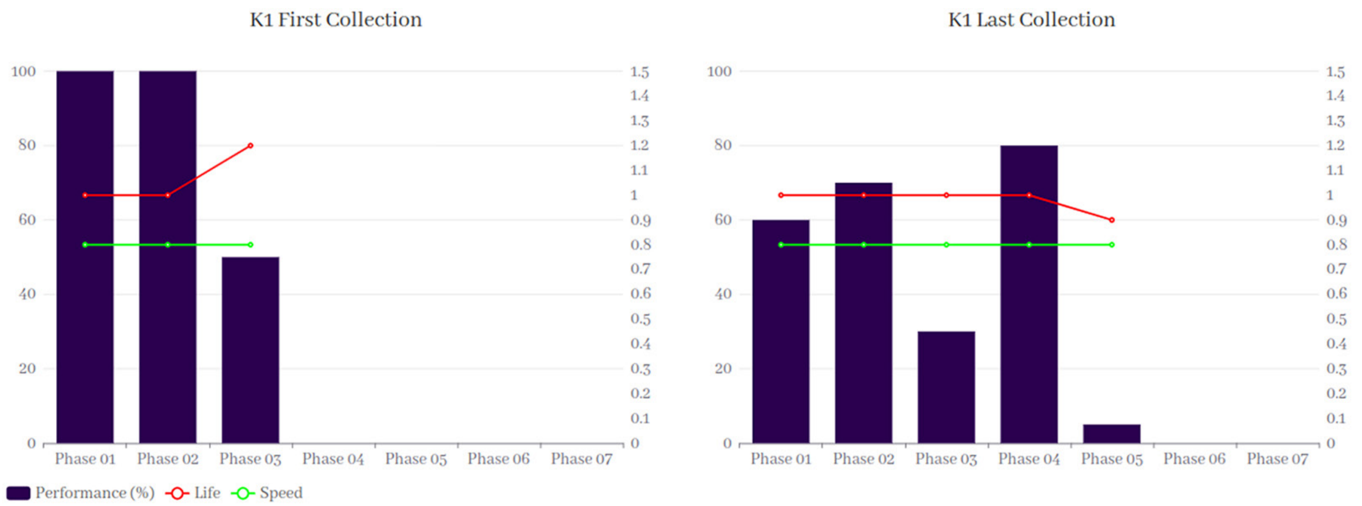

Fig. 5. *(Continued)*

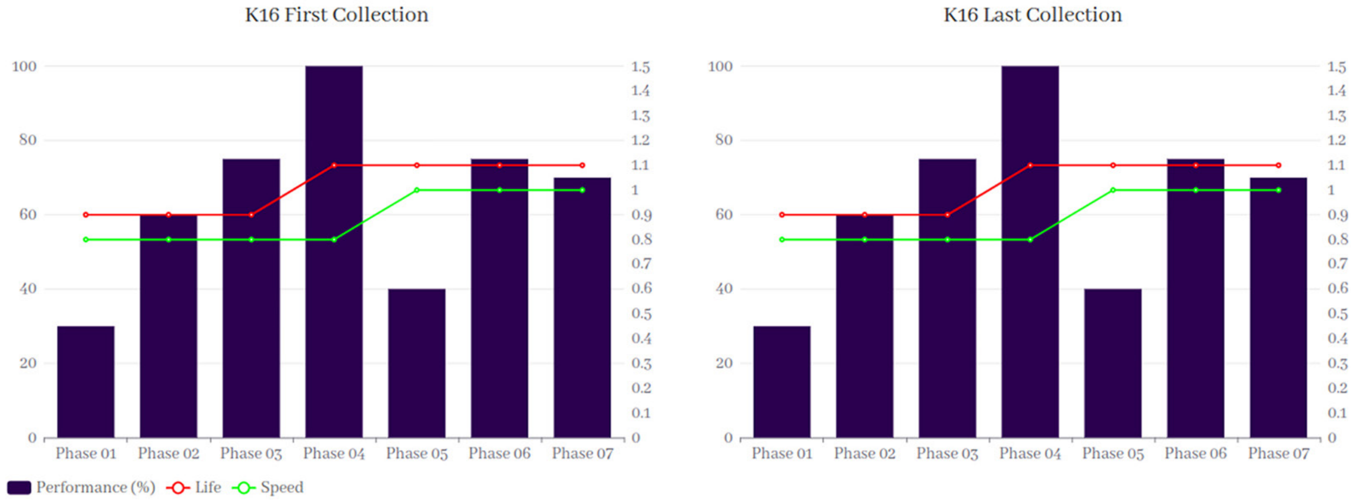

Fig. 5. K1's and K16's performance in SG Goblin Gold

K1, a student with moderate autism, exhibited declining performance throughout the data collection period, failing to progress beyond stage 3. His life modularization and speed graphs showed a downward trend, indicating difficulties in keeping up with the game's speed and complexity. This result aligns with research emphasizing the importance of adaptations and individualized support for children with moderate autism. K1 showed variable performance in reflex assessment over the collection periods. His ability to react to fast-moving enemies was challenging, but there was some consistency in his performance. Facing challenges, especially in stages 4 and 5, where they couldn't advance, made it impossible to assess concentration and peripheral vision.

In the case of K16, a student from a public school diagnosed with mild and high autism, consistent performance was observed over the six-week testing period. His life modularization and speed graphs showed positive progression, decreasing in difficulty as the game stages advanced to remain engaged. Furthermore, his recognition distance gradually decreased, indicating increased precision in visual focus. These results are in line with studies highlighting the importance of gradual challenges to promote skill development in children with autism.

8 CONCLUSIONS

The cognitive benefits derived from SGs are intricately tied to the contextual and social factors that surround their implementation. The study, focused on developing and evaluating SGs for enhancing cognitive skills, underscores the importance of analyzing the effectiveness of interventions within authentic learning environments. Emphasizing the interconnection between cognitive and motor functions, the research highlights the need to consider the impact of spatial and social contexts on the quality of interactions and the resulting outcomes. The integration of SAR technology, specifically combining ABA methodologies and PRT techniques, not only seeks to overcome intervention challenges but also aims to sustain children's interest and motivation, fostering effective learning experiences. Work contributes to a deeper un derstanding of the potential of SAR therapeutic programs and their role in personalized cognitive interventions for children with ASD.

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