Proposal of Serious Games and Assistive Robot to Aid Therapies of Children with Autism Spectrum Disorder

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***Abstract*—Assistive robots have been increasingly incorporated into therapies aimed at improving the quality of life of children with disabilities. Such robots have tools to stimulate social, cognitive and physical skills in the children, being able to promote improvements in these aspects. In this paper, we propose a new assistive robot, termed MARIA T21 (Mobile Autonomous Robot for Interaction with Autistics and Trisomy 21), which has been developed at UFES/Brazil. The robot is integrated with serious games, which work with joint attention, memory, communication, social interaction ability, cognitive and psychomotor development in children with Autistic Spectrum Disorder (ASD) and Down syndrome (DS). This work focuses on the analysis of the integration robot-serious games for children with ASD, demonstrating its benefits as facilitators of therapies.**

Keywords — Serious games, Assistive robot, Autism Spectrum Disorder, Down Syndrome.

I Introduction

A. Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder (ASD) refers to neurodevelopmental disturbances whose symptoms are often encountered in the first years of life, such as difficulties in social communication, verbal or non-verbal, and social interaction, in addition to repetitive and restricted patterns of behavior, interests and activities [1]. Signs of autism also include difficulty talking about personal feelings or understanding the feelings of others, lack of engaging in play with others, lack of eye contact and joint attention behavior, and sensitivity to physical contact [2,3].

The prevalence of ASD has steadily increased over the past few decades, due to changes in concepts, definitions, service availability and awareness of ASD in the lay and professional public [34]. In addition, this increase can be partially attributed to the current diagnostic criteria present in the Diagnostic and Statistical Manual of Mental Disorders 5ª edition that consolidated previously separated disorders [4]. According to World Health Organization (WHO), a global ASD prevalence of 1 child in 160 is estimated worldwide [5] or about 1% of world population [6]. However, the Center of Diseases Control and Prevention in the United States reports a higher prevalence of 1 in 54 8-year-old children [7].

Behavioral treatments can improve children's with ASD quality of life and independence, and early intervention is essential for a positive long-term result. Therapies include approaches that focus on the use of non-human partners to facilitate human-human social interaction [8].

B. Socially Assistive Robotics (SAR) and Serious Games (SGs)

Many studies highlight promising results in therapeutic interventions for children with ASD using robots. Socially Assistive Robotics (SAR) has helped in the diagnosis and practices that aim to stimulate social, cognitive, and physical skills as well as improve the effects of therapies in children with ASD [9]. These robots can be equipped with sensors and cameras to detect touch and child location and to move [10].

Serious games (SGs) are a combination of educational and entertainment tools used to train skills and compensate for difficulties [11]. Thus, SGs can assist in cognitive and psychomotor therapies [12,13]. Some studies [14-16] with SGs use projectors or screens and cameras that capture the child's movements to play using his/her own body. This can improve various individuals' cognitive skills since games stimulate problem-solving, decision making, information processing, creativity, and critical thinking [17]. Previously, SGs using projectors and cameras for child interaction were used at UFES/Brazil [12,14], which verified the effect of game therapies on the postural balance of children with Down Syndrome (DS). The mother of one child, aged 9 years, reported episodes of falling from her own height, presenting a deficient psychomotor profile (score of 08 in Vitor da Fonseca's Psychomotor Battery and 37 in the Berg Scale) in the initial assessment, which indicated a risk of falling. After the therapy with the robot, the child showed considerable improvement after 12 sessions [12].

C. Robot MARIA T21

N-MARIA (New-Mobile Autonomous Robot for Interaction with Autistics) is a robot developed at UFES/Brazil. It has locomotion capacity with two motorized wheels, which give it the ability to interact in a spatial way with the child as well as carry out programmed routes. Since the launching of this robot, new ideas emerged, such as the incorporation of serious games and extend its application in therapies for children with DS. Thus, a new version was developed, the robot MARIA T21 (Mobile Autonomous Robot for Interaction with Autistics and Trisomy 21) [19] addressed in this paper, which has features that enhance the Child-Robot Interaction (CRI) conducted using SGs. For example, coatings sensitive for physical contact, providing the robot with the ability to react positively to the child's touch, reinforcing this ability in children with ASD. Also, this robot has a projector of SGs, which can be played by the child and allow greater interaction. For this, the identification of movements is carried out by two cameras attached to the head and one camera in the chest. The robot can change its size to adapt to different children's heights and therapy proposals, being able to act like a friend with similar age as the child as well as an authority figure controlling the interaction. MARIA T21 can be easily transported and has the concept of repeatability, so similar robots can be produced to institutions that perform therapies of children with ASD or DS (Figure 1). It is worth commenting that MARIA T-21 incorporates contributions from the interdisciplinary development team, composed of a physiotherapist, a biologist, a biomedical engineer, and electrician engineers from the postgraduate programs in biotechnology and electrical engineering at UFES/Brazil.

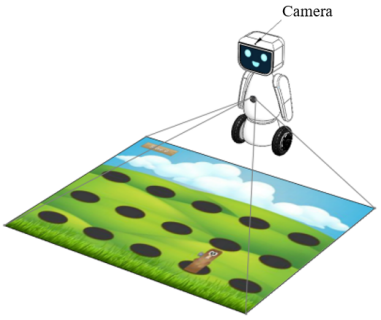

Figure 1. Robot MARIA T21 of UFES/Brazil [19]

The objective of this work is to describe an interaction protocol between the robot MARIA T21 and children with ASD, between 5 and 15 years, using SGs as a method for intervention in the capacity for joint attention, memory, communication, social interaction, cognitive and psychomotor development. This research was authorized by the UFES's Ethics Committee (number 1.121.638). In the following, this article is structured in three sections. Section 2 describes materials and methods, protocol and SGs of this study, including the scales used to assess the experiments. Section 3 presents the results with the application of MARIA T21 in therapies with children with ASD and a comparison between the proposed system and previous work in this area. Finally, the last section presents the conclusions about using the proposed protocol.

II. Materials and Methods

A. Participants

This study is composed of two groups, an experimental and a control group. The experimental group consists of children and teenagers of both sexes who have a clinical diagnosis for ASD, aged between 5 and 15 years, and who understand the verbal and/or visual commands needed to play with the SGs. These children are assisted by the institutions from Vitoria/Brazil specialized in the care of children with autism and down syndrome. Children with ASD who present concomitant neurological diseases, with a tendency to aggression and/or very agitated and who perform many stereotyped/repetitive movements are excluded from the study. The control group consists of typical children and teenagers of both sexes, aged 5 and 15 years. Parents or guardians of individuals in both groups must grant permission to participate in the study by signing the Free and Informed Consent Form.

B. Testing Protocol and Serious Games

The protocol consists of 8 game therapy sessions with 40 minutes, using 3 SGs per session, during 4 weeks between September and October 2021. Before the games start, the researcher explains and demonstrates to the child the correct way to use each one. During the interactions, the researcher aids whenever necessary and give verbal commands for carrying out the activities. The tests are carried out in a large room, at a constant temperature. Into the room are present the robot, the child, a parent or guardian, the researcher and an electrical engineer who controls the robot and the games.

Firstly, the robot MARIA T21 enters the test room accompanied by the researcher. When approaching the child, MARIA T21 asks the name and age of the child and introduces itself. The, it asks if the child wants to play. Subsequently, the researcher starts the game or issues a new invitation message if the child has not been convinced, so the projection is initiated. The game is interrupted when the child does not show interest after some attempts (assigned by the therapist). During the games, success rate, playing time, displacement and position of the child, facial expressions, attention in relation to activities as well as emotions using a thermal camera are evaluated.

The game "What is the Card?" aims to stimulate the child's knowledge about the numbers from 1 to 5 and the vowels, in addition to work on shared attention, imitation and interaction, which are abilities normally reduced in children with ASD (Figure 2). This game has three levels: in the first one, a number between 1 and 5 is projected at a time interval of up to 15 s. The time can be changed according to the child's evolution and improved response speed. Each number has a corresponding card that is shown by the child, in which a QR code on the cards allows the robot to identify whether the child showed the correct card or not. These numbers appear several times at random, and the sequence is completed when the child hits the number ten times.

At level two, the vowels (A, E, I, O, U) are projected at random until the child gets ten correct answers. Level three puts together the five numbers and the five vowels, each one being projected once at random, and the child must choose among the ten cards the one that is correct.

In case of a mistake, the robot says to the child, and encourages her/him to continue the game. Next, an audio message is issued saying that time is running out when there

are five seconds left. At the end of each level, when the child reaches ten correct answers and completes this stage, she/he is congratulated by MARIA T21. To finish the game, MARIA T21 says: “It was great to play with you!”. The sequence of actions is commanded by the researcher through a remote computer. The completion of the game generates a text report with the total number of hits and misses of the child, as well as execution time from start to finish or interruption of the game.

The game “Tightrope” aims to train the skills of focus and shared attention, as well as aspects of postural balance, proprioception and motor coordination (Figure 3). The game features an image projection of a rope attached to two ends, simulating a high height where the child must walk until reaching the other side.

Figure 2. Cards for the game “What is the Card?”

Source: own source, 2021

This game consists of three levels: the first one in which the child must walk through the image of the rope, holding a ball until she/he reaches the other side of the cliff. On the second level, the child must make the crossing holding the ball until she/he reaches the other side of the cliff, and along the way images of birds suddenly appear to become a distraction to the task. At the third level, when performing the task, a part of the rope image starts to flash. This is done to encourage the child to walk faster to the end of the path.

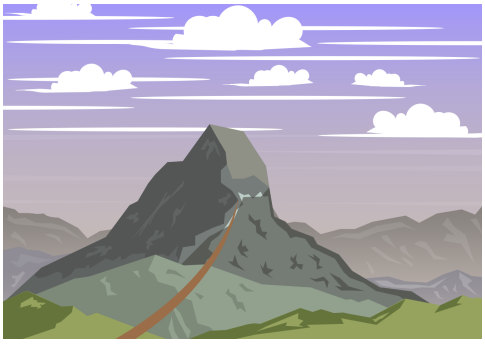

Figure 3. Game “Tightrope”

Source: own source, 2021

“What is the Character?” is a game in which the child watches a stretch from the children's movie “Inside Out” for approximately 10 min, displayed on the tablet that serves as the face of MARIA T21. This movie was chosen because some characters represent the emotions of joy, disgust, sadness, anger and fear (Figure 4).

After showing the video, the robot asks the child questions about the characters and other items presented in the video, for example, the emotions of some characters. From each question the child must choose the corresponding card, where each one has a QR code that allows MARIA T21 to identify the correct card. During the game, MARIA T21 can give tips for the child to be able to find the cards. In this interaction, child's attention, concentration and memory are worked on and evaluated, as well as the ability to discriminate between different characters and emotions.

Figure 5. Cards for the Game “What is the Character?”

Source: figures from movie Inside out - Disney

The game “Sound Sequence” works with divided and shared attention, as well as children's memory and discrimination of stimuli such as emotions, sounds and colors. For this, MARIA T21 projects in front of the child eight shapes with different expressions and colors. Subsequently, it asks for the child's attention and flashes some of the figures making different sounds for each of them. The child should then touch the projected figures by repeating the sequence shown by the robot (Figure 5).

In the first level, the sequence has two items, in level two it has three items, and so it continues to increase until level seven with the eight figures flashing. This way, each level has greater complexity than the previous one. MARIA T21 identifies if the child followed the correct sequence, and in case of error, it gives a second chance. At the end of the game, a score is assigned, in which 1 is given for each hit on the first attempt, and 0.5 when the hit occurs on the second attempt. A text file is generated with the total hits and misses, the time spent to execute the game and the child's score.

Figure 5. Game “Sound Sequence”

Source: own source, 2021

The game “Sensory Rug” aims to stimulate physical contact with different textures, which is usually a barrier for children with ASD, in addition to training motor coordination and proprioception. In this game, a rug is used, which works as a flying vehicle (or a boat, depending on the scenario). That rub contains distinct areas with load cells for plantar adhesion analysis. These areas act as direction controls since the projection made by MARIA T21 in front of the child takes her/him on a kind of adventure. This control allows the child to avoid “obstacles” that appear, for example, birds, airplanes and rain clouds when he/she comes to an adventure in the skies, rocks, fishes, and rapid currents in water adventures (Figure 6).

The mechanism to avoid objects is based on the child's position. So, depending on the obstacle the child moves to the right or left of the rug, and the adventure vehicle moves in the corresponding direction. The center of the rug is a neutral zone, which corresponds to the command to keep the course stable. In case of resistance to any of the textures and the absence of the child's displacement, the vehicle collides with the obstacles. MARIA T21 keeps the information about the time spent in each sensory area, total collisions of the

game, success rate, regions with which the child has less physical contact, facial expression of resistance/repulsion to the touch of each texture, emotion expressions and attention to the game.

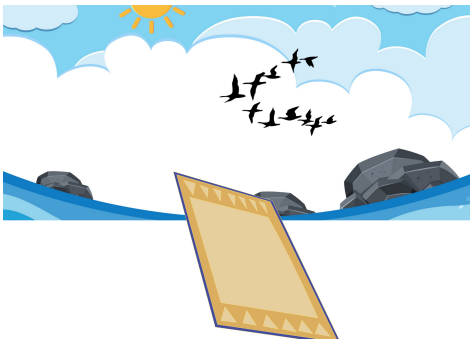

Figure 6. Game “Sensory Rug”

Source: own source, 2021

The “Animals Detective” game aims at training divided and shared attention, proprioception, motor coordination, and postural balance. A forest is projected, and the faces of several animals appear, for example, a monkey, a giraffe, a lion, among others. The robot rotates on its own axis next to the child, that should walk around the robot and explore the projected scenario, performing the tasks. With the feet, the child must indicate the animals that appear on the scene, as the game progresses the total number of animals and the difficulty of the game increases (Figure 7).

Figure 7. Game “Animals Detective”

Source: own source, 2021

In this process, some scales are used to quantitatively assess the interaction of children with ASD with the robot and the SGs. Children development, system usability and efficiency to stimulate target skills in the participants are evaluated using the following scales: Goal Attainment Scaling (GAS), Autism Treatment Evaluation Checklist (ATEC), Child Behavior Checklist (CBCL) and System Usability Scale (SUS).

GAS is a method for scoring in a standardized way goals achieved during an intervention [20]. Each goal is scored according to the success in accomplishing it, ranging from -2 (performed much worse than expected) to +2 (performed much better than expected), with 0 indicating the expected performance. This scale is also used to assess “cognitive rehabilitation” [21]. In this work, the objectives are: “Look at the robot”, “Touch the robot”, and “Interact with the mediator”, which are important aspects in children with ASD, due to their difficulty of making eye contact, physical contact, and communication (Table 1).

The success rate of the achievement of the objectives is calculated by:

$$T = 50 + C_x \sum x_i ,$$

where C_x refers to the coefficient of general objectives (for three objectives it corresponds to 4.56), and x_i is the GAS score for each objective. T equal to 50 corresponds to the expected performance level; T greater than 50 reflects better than expected performance; and T below 50 reflects poor performance [22].

ATEC is a form designed to be completed by parents or caretakers. It consists of 4 subtests: I. Speech/Language Communication; II. Sociability; III. Sensory/ Cognitive Awareness; and IV. Health/Physical/ Behavior. It basically provides several subscale scores as well as a total score to be used for comparison after therapy [23].

CBCL is a 100-item questionnaire that evaluates children in various domains of global psychopathology. Parents should rate the frequency of specific behaviors on a three-point scale. The score obtained provides data on Internalization, Externalization and Total Problems (T). When T is greater than or equal to 63, it is considered clinically significant; values between 60 and 63 identify a borderline clinical range; values below 60 are considered non-clinical [24]. CBCL has been used to measure changes in children's behavioral and emotional states before and after interventions with robotic systems [25]. In this study we use the Brazilian version of CBCL.

Through SUS, parents or guardians evaluate the use ease of the robot and SGs as a therapeutic tool for children with ASD. SUS has ten items (odd-numbered items worded positively; even-numbered items worded negatively). For example, 1. I think that I would like to use this system frequently; 2. I found the system unnecessarily complex. For each item, a score of 1 (“strongly disagree”) to 5 (“strongly agree”) is assigned, with number 3 being the absence of a response. For odd items, 1 is subtracted from the score given by the user, and for even items, the value of the given score is subtracted from 5. The resulting values are added up and multiplied by 2.5. The total value ranges from 0 to 100, in which good results are obtained when the average score of 68 is exceeded [26].

TABLE 1. GAS FOR THREE GOALS

		Goals		
Expected achievements	**Punctuation**	**Look at the robot**	**Touch the robot**	**Interact with the mediator**
Much worse than expected result	-2	Look at the robot for less than 30 seconds and show repulsion	Do not touch the robot	Seeming not to understand the mediator's commands and not to carry them out
Worse than expected result	-1	Looking at the robot for less than 30 seconds and not being interested	Touch the robot for less than 5 seconds	Seem to understand the mediator's commands, but do not carry them out, even if encouraged
Expected outcome	0	Look at the robot for more	Touch the robot for more	Understand the commands and

		than 30 seconds and maintain eye contact with the monitor	than 5 seconds	carry them out, encouraged by the mediator
Better than expected result	+1	Look at the robot for more than 30 seconds and pay attention to the monitor	Touch the robot for more than 5 seconds and pay attention to the monitor	Understand the mediator's commands and carry them out spontaneously
Much better result than expected	+2	Look at the robot for more than 30 seconds and go towards it spontaneously	Touch the robot for more than 5 seconds and play with it	Understand the commands and perform them spontaneously and together with the mediator

III. Results and Discussion

Children with ASD seem to have a strong interest in robots, due to the simple interaction characteristics that cause them less anxiety [27]. In this sense, an increasing number of studies have explored the opportunities for technology-based intervention to support children and teenagers with ASD. Computer-based technologies, virtual reality, mobile phone and tablet applications, as well as robotics, are being considered promising approaches for these interventions [13].

Basically, the purpose of researching the use of a robot for children with ASD is to induce targeted behavior, such as joint attention, imitation, emotional expression or spontaneous interaction; teach special tasks to children; and study the quality and quantity of interactions between a child and a robot, which could help doctors in their diagnosis and therapies [11].

Therapies of children with ASD requires intensive intervention and is a challenge in terms of human resources, costs and time. The intervention hours allocated to children with ASD are generally less than the actual need (20h/week). Therefore, game platforms can be an interesting solution to increase the therapy time of these children and to involve caregivers in the intervention [28].

Currently, there are many applications on portable devices that aim to be playful and teach specific skills, among them SGs that work on the main difficulties of the individual with ASD, such as social skills and emotion recognition [11]. However, many SGs available have some limitations, as limited performance under real interactive conditions, and target individuals with high functioning ASD [24].

Thus, the development of this new robot, MARIA T21 together SGs seek to directly impact children with ASD, therapists and family members. Bearing in mind that for the robot to fulfill its purpose it is important that children feel comfortable with it and see it as a "friend" [29], we seek to develop a simple and friendly appearance that captivates children.

The dialogues and positive reinforcements provided by MARIA T21 seek to align with the interests of children, providing information for the player to monitor their progress in games and to maintain interest [11]. The automated evaluation system is capable of extracting quantitative data, characterizing the child's performance in each game and, thus, providing the characteristics of the temporal evolution of performance [28].

Research has increasingly shown the benefit of SGs and/or interaction with social robots for the therapy of children with ASD. In this sense, the review of [30] reports the clinical efficacy in the use of robots to increase social interactions and involvement throughout the sessions and improvements in the recognition of emotion, understanding and taking emotional perspective in children with ASD.

Studies conducted by [16] used SGs to support therapy sessions and found an improvement in target behaviors related to social interactions, such as smiling, making eye contact and sharing emotions. Another example is the Gaming Open Library Intervention for Autism at Home, which is based on the stimuli of imitation and joint attention through 11 games. As a result of the intervention, it was observed a decrease in parental stress, progress in the skills to perform most games, an improvement in the scores of the Autism Diagnostic Observation Schedule (ADOS), Vineland's socialization score, and the total score of the Child Behavior Checklist, indicating that the therapy was positive [24].

Research developed at UFES/Brazil [12,17,18] using the robot N-MARIA and SGs has also demonstrated good results for children with ASD and DS, respectively, indicating the promising perspective of the current study. Therefore, we describe here a protocol for child-robot interaction using SGs cited, which aim to stimulate some cognitive aspects of children with ASD, such as concentration, memory, and divided and shared attention, allowing them to develop physical aspects such as motor coordination, proprioception and postural balance. Finally, this study was conducted to evaluate the robot's capacity for acting assisting therapists and seeking to improve the life quality of children with ASD.

In this sense, it is crucial to use scales to assess the children's development and the performance of the robot and SGs. GAS assesses the interaction of children with ASD and the robot using SGs; ATEC and CBCL evaluate the development of these children and, finally, the usability and efficiency of the system are evaluated by SUS.

In the game "What is the Card?" the aim is to work on shared attention, imitation and interaction, normally reduced in children with ASD, in addition to stimulating the child's knowledge about the numbers from 1 to 5 and the vowels. In this process, the child should be attentive to the words of MARIA T21 and organize themselves to show the correct card. In the game "What is the Character?" the child should carefully watch the excerpt of the children's movie "Inside Out", and be attentive to the characters and their emotions. Subsequently, the child should choose the cards that match the questions asked by MARIA T21. Therefore, the child's attention, concentration and memory are worked on, as well as the ability to discriminate different stimuli and emotions.
In the game "Sound Sequence" the child needs to reproduce the sequence made by the robot touching different figures with varied expressions and colors. This game addresses divided and shared attention, as well as the children's memory and discrimination of sound and colors.

The "Sensory Rug" helps the children with ASD to have contact with different textures, which can represent a barrier

for these children, in addition to training their motor coordination and proprioception. The different areas of the rug act as direction controls to avoid obstacles in the game. The game “Tightrope” aims to train focus, shared attention, postural balance, proprioception and motor coordination. In this game, the child should move along a virtual rope with the presence of distractions in the projection and with time for the rope to disappear, encouraging the acceleration of the walk.

The animals that appear in the game “Animals Detective” stimulates the child's movement and walk with MARIA T21, the divided and shared attention, proprioception, motor coordination, and postural balance. It is worth commenting that all these aspects worked by the SGs are of paramount importance for the development of children with ASD.

A. Pilot test

So far, we have carried out a pilot test of child-robot interaction, using the games “What is the Card?” and “Animals Detective”. Two children participated in the tests, they will be called child 1 and child 2, the first with twelve years and the second with five. During the interactions, they initially showed fear of the robot, a situation that may be related to the MARIA T21 entering the room where the child was, therefore, in the next tests we will start the session with the robot inside the room.

Child 1 played both games for approximately an hour of interaction, showing interest and good performance during the game “What is the Card?”. Regarding the game “Animals Detective”, the child had difficulty understanding the stages of the game (Figure 8). It is noteworthy that in the interaction the child was attentive to the MARIA T21, saying it was your friend and at the end of the session she resisted going away. Child 2 interacted with MARIA T21 for twenty minutes, using only the game “What is the Card?”. In this case, we verified the child's good resourcefulness, who later reported to the mother that she would like to play with the robot again.

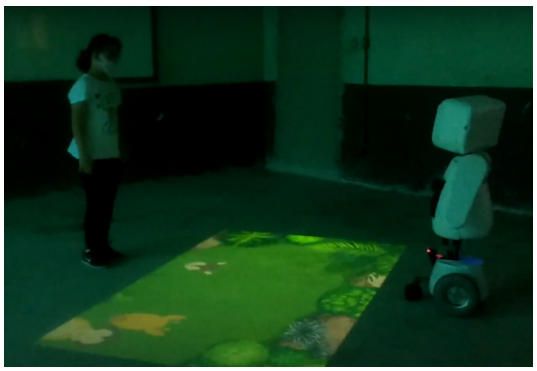

Figure 8. Pilot test of CRI using serious game held at UFES/Brazil
Source: own source, 2021

IV. Conclusions

In view of the promising results found in the research carried out at UFES/Brazil using robots and SGs, it is believed that the combination of these technologies and the integration of new tools can benefit cognitive and psychomotor therapies of children with ASD, since this association has a motivating and facilitating effect, both for the child and the therapist. Still, children subjected to electronic games tend to become experts in the game, which indicates that the games can help them in the topics covered here, improving deficit aspects.

MARIA T21 has demonstrated to be a playful therapeutic collaboration tool, capable of providing greater interaction between body and mind of children with ASD, as well as greater engagement during therapies. Due to the sensing onboard the robot, safe and reliable parameters of physical evaluation and monitoring of the evolution of the treatment are generated in response to the therapies. It is expected that this research has social, therapeutic and scientific relevance, and also improves and optimizes the provision of care services to children with ASD.

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