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Robot enhanced interventions and repetitive and stereotyped behaviors in children with Autism Spectrum Disorder: a scoping review

Intervenções aprimoradas por robôs e comportamentos repetitivos e estereotipados em crianças com Transtorno do Espectro do Autismo: uma revisão de escopo

Intervenciones mejoradas con robots y comportamientos repetitivos y estereotipados en niños con Trastorno del Espectro Autista: una revisión de alcance

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Abstract
Repetitive and stereotyped behaviors (RSBs) are core symptoms of Autism Spectrum Disorder (ASD), and they affect the functionality of individuals with ASD. Robot assisted therapy can be beneficial for children with ASD in various ways, but relevant research focusing specifically on robot enhanced interventions (REIs) for RSBs in children with ASD has been limited. A scoping review was conducted to explore the role of REIs on RSBs of children with ASD and to investigate the components of REIs focusing on RSBs of younger and older children with ASD. A literature search was made in the databases of Scopus, PubMed, Web of Science, EBSCO, MEDLINE, and Google Scholar, using keywords pertaining to robots, ASD, RSBs, and children. Of the 89 studies identified, 10 met the inclusion criteria. They involved 99 participants aged 3-14 years (mean 7.27 years) from six countries on three different continents. These studies varied with respect to sample size, the research design, the robot used, the length of intervention, the training and the type of measurement. Following the application of most REIs, the participants showed reduction in RSBs. Only one study reported that REI led to some increase in stereotyped behaviors in children with ASD and one detected no training-related changes in repetitive behaviors. The review findings indicate the potential of REIs for reducing RSBs in children with ASD, but the relevant studies were diverse, and controlled studies with larger samples of children and rigorous design are needed to clarify their impact.
Keywords: Autism Spectrum Disorder; Repetitive and stereotyped behaviors; Robots; Robotics; Interventions; Children.

Resumo
Comportamentos repetitivos e estereotipados (CREs) são principais sintomas do Transtorno do Espectro Autista (TEA), e afetam a funcionalidade de indivíduos com TEA. A terapia assistida por robôs pode ser benéfica para crianças com TEA de várias maneiras, mas pesquisas relevantes com foco especificamente em intervenções aprimoradas por robôs (IARs) para CREs em crianças com TEA tem sido limitadas. Uma revisão de escopo foi conduzida para explorar o papel dos IARs em CREs de crianças com TEA e investigar os componentes de IARs com foco em CREs de crianças mais jovens e mais velhas com TEA. Uma pesquisa de literatura foi feita nos bancos de dados Scopus, PubMed, Web of Science, EBSCO, MEDLINE e Google Scholar, usando palavras-chave relativas a robôs, TEA, CREs e crianças. Dos 89 estudos identificados, 10 atenderam aos critérios de inclusão. Eles envolveram 99 participantes com idades entre 3 e 14 anos (média 7,27 anos) de seis países em três continentes diferentes. Esses estudos variaram em relação ao tamanho da amostra, ao desenho da pesquisa, ao robô utilizado, ao comprimento da intervenção, ao treinamento e ao tipo de medição. Após a aplicação da maioria dos IARs, os participantes apresentaram redução nos CREs. Apenas um estudo relatou que o IAR levou a algum aumento nos comportamentos estereotipados em crianças com TEA e um detectou nenhuma mudança relacionada ao treinamento em comportamentos repetitivos. Os achados da revisão indicam o potencial de IARs para a redução de CREs em crianças com TEA, mas os estudos relevantes foram diversos, e estudos controlados com amostras maiores de crianças e design rigoroso são necessários para esclarecer seu impacto.
Palavras-chave: Transtorno do Espectro Autista; Comportamentos repetitivos e estereotipados; Robôs; Robótica; Intervenções; Crianças.

Resumen

Los comportamientos repetitivos y estereotipados (CREs) son síntomas centrales del Trastorno del Espectro Autista (TEA) y afectan la funcionalidad de las personas con TEA. La terapia asistida por robot puede ser beneficiosa para los niños con TEA de varias maneras, pero la investigación relevante que se centra específicamente en las intervenciones mejoradas por robot (IMR) para los CREs en niños con TEA ha sido limitada. Se realizó una revisión del alcance para explorar el papel de los IMR en los CREs de los niños con TEA e investigar los componentes de los IMR centrándose en los CREs de niños más pequeños y mayores con TEA. Se realizó una búsqueda bibliográfica en las bases de datos Scopus, PubMed, Web of Science, EBSCO, MEDLINE y Google Scholar, utilizando palabras clave relacionadas con robots, TEA, CREs y niños. De los 89 estudios identificados, 10 cumplieron los criterios de inclusión. Participaron 99 participantes de 3 a 14 años (media de 7,27 años) de seis países de tres continentes diferentes. Estos estudios variaron con respecto al tamaño de la muestra, el diseño de la investigación, el robot utilizado, la duración de la intervención, el entrenamiento y el tipo de medición. Después de la aplicación de la mayoría de los IMR, los participantes mostraron una reducción en los CREs. Solo un estudio informó que IMR condujo a un cierto aumento en los comportamientos estereotipados en niños con TEA y uno no detectó cambios relacionados con el entrenamiento en los comportamientos repetitivos. Los hallazgos de la revisión indican el potencial de los IMR para reducir los CREs en niños con TEA, pero los estudios relevantes fueron diversos, y se necesitan estudios controlados con muestras más grandes de niños y un diseño riguroso para aclarar su impacto.

Palabras clave: Trastorno del Espectro Autista; Comportamientos repetitivos y estereotipados; Robots; Robótica; Intervenciones; Niños.

1. Introduction

Autism Spectrum Disorder (ASD) is a developmental condition characterized by deficits in social communication and interaction as well as restrictive and repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). Repetitive and stereotyped behaviors (RSBs) are core symptoms of ASD, and the term includes a variety of behaviors, such as stereotyped or repetitive motor movements, use of objects or speech, compulsive behavior, perseveration, obsessions, rituals, sameness, restricted behaviors, stereotyped use of language, and self-injury (Staal, 2015; Watt et al., 2008).

There is often difficulty in classifying behaviors into a single category, as they show many similarities with each other, and the boundaries are fluid (Staal, 2015). Turner (1999) subdivided this broad range of RSBs into “lower-level” behaviors, characterized by repetition of movements such as dyskinesias, tics, stereotyped movements, repetitive manipulation of objects and repetitive forms of self-injurious behavior, and “higher-level” behaviors, such as object attachments, sameness, repetitive language, and restricted interests (Turner, 1999).

Individuals with ASD who function at a lower level are more likely to display “lower-level” behaviors while those with higher cognitive abilities tend to manifest “higher-level” behaviors, presumably because these require a higher level or complex skills (Turner, 1999; Watt et al., 2008). It has become apparent that in addition to the IQ score, there may be differences in RSBs depending on age. Younger children are more likely to display repetitive motor behavior, such as truck movement, while in older children, more complex movements, such as filling, are observed (Ringdahl, 2011).

Various theories have been put forward about the manifestation of RSBs in individuals with ASD, including the suggestion of Lovaas et al. (1987) that repetitive behavior is maintained by automatic reinforcement, that is, it consists of the result that the behavior itself produces when it occurs (Iwata et al., 1994). RSBs can be maintained by social reinforcement, and have also been described with neurological explanations (Mulligan et al., 2014). RSBs affect the functioning of children with ASD and distract them from successful interaction with their environment. The presence of these behaviors has an impact on their acquisition of social and academic skills (Staal, 2015; Tiger et al., 2009), and for this reason, research focused on interventions that may reduce RSBs in children with ASD is important.

Robot assisted therapy can be beneficial for children with ASD, who show special interest for technology. The environment of their interaction with the robot is more controlled and predictable than that with the human, and individuals with ASD can feel safe, and become less frustrated when interacting with robots (Feil-Seifer & Matarić, 2009; Sartorato et al.,

2017). The simplicity of robots and their ability to repeat patterns in a foreseeable way correspond to the characteristics of children with ASD, who seek sameness and who, themselves, manifest repetitive behaviors (Costa et al., 2018). It has been observed that children with ASD show better results in terms of the desired target behavior when interacting with a robot than in virtual learning environments. This is due to the flexibility of robots, and the integration of multisensory elements, such as realistic 3-dimensional body movements (Sartorato et al., 2017). Robots have features that make the interaction less complex, and children with ASD prefer to engage with the robot rather than with a human partner (Cabibihan et al., 2013).

Robots can be adapted to meet the unique needs of each child. Through structured activities, they act as reinforcement in enhancing specific skills, and provide support and positive feedback, in order for children with ASD to achieve the desired aim (Cabibihan et al., 2013), with improvement in their social and communication skills (Cabibihan et al., 2013; Kim et al., 2013; Sartorato et al., 2017). Despite the positive effects observed in robot enhanced interventions (REIs), there is still ambiguity as to their efficacy in ASD intervention (Begum et al., 2016). Pennisi et al. (2016), exploring the usefulness of robots in a treatment program for individuals with ASD, observed improvement in social behavior and language skills during their interaction with the robot, and a reduction in RSBs. Damianidou et al. (2020) investigated the impact of the use of robots on social communication and interaction in individuals with ASD, and Jouaiti and Hénaf (2019) observed the effects on motor rehabilitation.

Previous reviews have not focused specifically on the role of REIs on RSBs in children with ASD. As RSBs are observed in most children with ASD, and significantly affect their functionality (Staal, 2015), limiting their academic and learning opportunities and their ability to successfully interact with the social environment (Cunningham & Schreibman, 2008; Tiger et al., 2009; Watt et al., 2008), the aims of this scoping review were: 1) to explore the role of the REIs on RSBs of children with ASD and 2) to investigate the components of REIs on RSBs in younger and older children with ASD.

2. Methodology

The methodology for the current review was based on the PRISMA guidelines for scoping review (Tricco et al., 2018). Scoping reviews are used to map the current literature, summarize the key points, identify research gaps, and present proposals for future research (Peters et al., 2020; Tricco et al., 2016). This type of review is more suitable for exploring and expanding knowledge in an emerging field (Peters et al., 2020). Robot assisted autism therapy is a new and constantly evolving field, but its role in reducing RSBs has not been extensively investigated, and not enough adequate data sets are available to draw definitive conclusions. Scoping review, rather than a systematic review, was chosen as the research aim was identification, presentation, understanding and discussion of the main points in the current literature in this area.

2.1 Search Strategy

A literature search was conducted in the databases of Scopus, PubMed, Web of Science, EBSCO, MEDLINE, and Google Scholar, using a combination of the keywords "Robots or Robotics" and "Autism or Autism Spectrum Disorder or ASD", and terms referring to "Child" (e.g., children, preschool, elementary school, middle school, boys and girls) and "Stereotyped or Repetitive behaviors". RSBs included both specific words describing repetition of movement (e.g., repetitive manipulation of objects, stereotyped movements, and repetitive forms of self-injurious behavior) and broader terms including higher-level behaviors (e.g., object attachments, repetitive language, and limited interests). The combination of the above keywords was applied to each database from 2001 up until August 2021. Table 1 provides an overview of the research strategy applied in the databases research.

Table 1. Combinations of keywords used in the electronic search in PubMed.

"Robots"[mh] OR "robotics"[mh] OR "robot*"[tw]
AND
"Autism Spectrum Disorders"[mh] OR "Autism"[mh] or "Autis*"[tw] OR "ASD"[tw]
AND
"Child"[tw] OR "child*"[tw] OR "school child"[tw] OR "school child*"[tw] OR "preschool"[tw] OR "kindergar*"[tw] OR "elementary school*"[tw] OR "primary school*"[tw] OR "middle school*"[tw] OR "secondary school*"[tw] OR "boy*"[tw] OR "girl*"[tw]
AND
"Stereotypy"[mh] OR "stereotyped behavior"[tw] OR "stereotyped behaviors"[tw] OR "repetitive behavior"[tw] OR "repetitive behaviors"[tw] OR "repetitive manipulation"[tw] OR "stereotyped movement"[tw] OR "stereotyped movements"[tw] OR "repetitive self-injurious behavior"[tw] OR "attachments"[tw] OR "repetitive language"[tw] OR "limited interest"[tw] OR "limited interests"[tw]

Source: Authors.

2.2 Selection of Relevant Publications

Specific titles and abstracts of the studies retrieved from database search were screened by the two authors based on the following criteria:

Inclusion criteria:

- The publication is a peer-reviewed study, conference proceeding or paper,
- The publication is in English,
- The intervention reported focuses on children aged 3–14 years with ASD,
- The study incorporates a robot in intervention with children with ASD,
- The study incorporates measurements for RSBs,
- The study assesses outcomes of RSBs in children with ASD.

Exclusion criteria:

- The publication is not an empirical study. Book chapters, posters, and review articles were excluded from the current review,
- The publication includes participants with Asperger Syndrome, Rett Syndrome, Childhood Disintegrative Disorder, Pervasive Developmental Disorder not Otherwise Specified,
- The publication does not report on intervention,
- The publication describes only robot development,
- The publication examines only social communication and emotional outcomes of robot intervention (e.g., eye contact, imitation, emotion recognition).

2.3 Data Extraction

After the initial screening of the titles and abstracts, and references to other relevant studies, the second author reviewed separately the studies to decide if they met the inclusion criteria. In the cases where inclusion in the review was not clear, the first author reviewed the study independently.

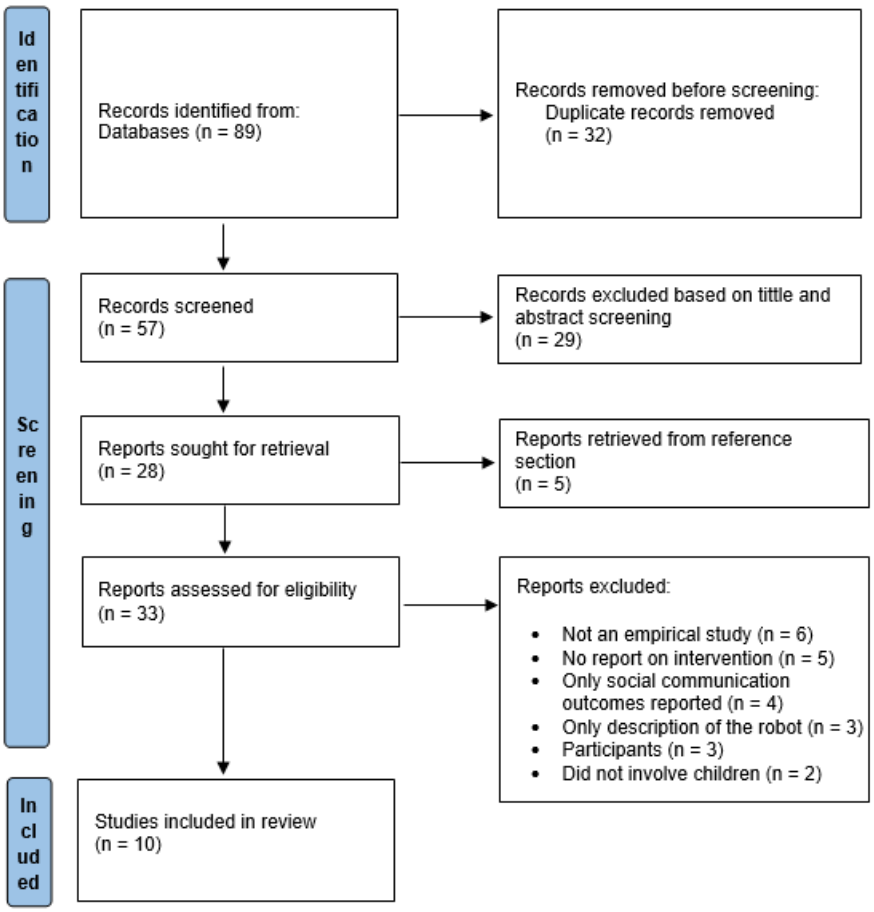
As agreement between the two authors was 100%, there was no need for a third examiner to intervene. All the studies included in the review provide data on the research design, the participants (number, gender, age, diagnosis, IQ scores), the type of robot, the country, the context of the intervention, the duration, the training, the types of measurements and the outcomes.

2.4 Search Results

This initial search revealed 89 studies, of which 32 were common and were removed. The titles and abstracts of the remaining studies were screened for inclusion in the review, by the two authors. This process led to 28 studies for full-text screening.

The reference section of the remaining studies was checked thoroughly and other relevant articles were investigated, resulting in 5 additional studies. The 28 initial and the additional 5 studies were reviewed, taking into account the inclusion and exclusion criteria. After full-text screening, 23 studies that did not meet the inclusion criteria, were removed. The 10 remaining studies were included in the final analysis. Figure 1 depicts the process and the results of the research strategy.

Figure 1. Prisma Flowchart depicting the literature research and selection of studies for review.



Source: Authors.

3. Results and Discussion

3.1 Characteristics of participants

Data on the number, gender, age, diagnosis, and IQ scores of the participants were provided for most of the studies included in the review. The number of participants in the studies ranged from 2-36 and the total was 99, of which 89 were males and 10 females. Only one study did not state the gender of the participants (Ismail et al., 2012). The participants were children and young teens who had been diagnosed with ASD; the age range was 3-14 years and the mean age 7.27 years. In three studies, the researchers reported that the participants were low-functioning (Duquette et al., 2008; Shamsuddin et al., 2013; Taheri et al., 2021), while in one they were specifically described as high-functioning (Shamsuddin et al., 2012). In the study of Taheri et al. (2018), the participants were a pair of high- and low-functioning fraternal twins (Taheri et al., 2018). IQ scores were reported in four of the ten studies (Costa et al., 2018; Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013). The characteristics of the participants in the studies reviewed here are presented in Table 2.

3.2 Country of study

The ten studies included in the review took place in six countries on three continents. Three studies were carried out in Malaysia (Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013), two in the USA (Srinivasan et al., 2015; Stanton et al., 2008) and Iran (Taheri et al., 2018; Taheri et al., 2021) and one in Canada (Duquette et al., 2008), Luxemburg (Costa et al., 2018) and Romania (David et al., 2020). The distribution indicates the worldwide research interest in studying the effect of REIs on RSBs in children with ASD. The research data from a variety of countries and cultures provide important insights into how interaction with robots affects children with ASD.

3.3 Intervention components

3.3.1 Robots used

Six different robots were used in the studies included in the review, the majority of which were anthropomorphic robots (Costa et al., 2018; David et al., 2020; Duquette et al., 2008; Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013; Taheri et al., 2018; Taheri et al., 2021), while one study used a non-anthropomorphic animal-like robot (Stanton et al., 2008) and one a combination of an anthropomorphic and non-biomimetic mobile robot (Srinivasan et al., 2015). The robot most commonly used was the humanoid robot NAO, which was used in seven of the ten studies. NAO was developed by Aldebaran Robotics, a French company. It is a robot with 25 degrees of freedom, with seven sensors located on the head, hands, and feet, sonars, and an inertial unit to perceive its environment and to locate itself in space. It is equipped with two cameras for identification of objects or faces, four microphones, and speakers to enable it to interact with people (SoftBank Robotics). The robots Tito, Alice-R50, QTrobot, AIBO, and RovioTM were each used in one study.

3.3.2 Context

All of the studies were conducted in a controlled environment. Most of the study interventions took place in a room located either in a university (Taheri et al., 2018; Taheri et al., 2021) or in a center for children with ASD (Costa et al., 2018; David et al., 2020; Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013). In two of the ten studies, only the experimental room is mentioned, without its location (Duquette et al., 2008; Stanton et al., 2008), and one was conducted in the home environment (Srinivasan et al., 2015).

3.3.3 Duration

The intervention length ranged from 4.3 minutes (Costa et al., 2018) to 45 minutes (Srinivasan et al., 2015), and the duration of the studies ranged from a single session (Costa et al., 2018; Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013; Stanton et al., 2008) to 32 sessions over 8 weeks (Srinivasan et al., 2015). The frequency of exposure of the participants in the longer interventions was three (Duquette et al., 2008) or four times per week (Srinivasan et al., 2015), and in one study daily (David et al., 2020).

3.3.4 Training

In most studies, the researchers used training involving imitation games (Costa et al., 2018; Srinivasan et al., 2015; Taheri et al., 2018; Taheri et al., 2021), including facial expressions, body movements, familiar actions with or without objects (Duquette et al., 2008), and interpersonal synchrony-based games (Srinivasan et al., 2015). Some researchers used simple modules of interaction with the robot, including verbal communications, simple physical actions, and interesting sounds (Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013). Imitation is used in therapy to promote better body awareness, sense of self and coordination (Costa et al., 2018).

They also used turn-taking games (Taheri et al., 2018; Taheri et al., 2021) or tasks on a touchscreen device (David et al., 2020), behavioral interactions with the robot (e.g., holding it and rolling the ball to it; Stanton et al., 2008) and other therapeutic games targeting various different cognitive skills, such as joint attention, social skills, eye-contact (Taheri et al., 2018), as well as music-based games (Taheri et al., 2021).

3.3.5 Type of measurement

The studies included in the review used a variety of standardized and non-standardized measurements to evaluate the effect of REIs on the RSBs in children with ASD. The standardized measurement used was the Gilliam Autism Rating Scale (GARS) (Stanton et al., 2008), and specifically the Stereotyped Behaviors Subscale (Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013; Taheri et al., 2018; Taheri et al., 2021).

Non-standardized measurements used in the studies were observations of specific stereotyped behaviors (Costa et al., 2018) including repetitive body movements, posture, or utterances (David et al., 2020) such as rocking, swaying, head rolling, arm flapping or shaking, finger flicking, and leg shaking (Srinivasan et al., 2015). Observations were also recorded of sensory behaviors, including repetitive movements with objects (e.g., spinning, smelling, throwing objects), negative behaviors, including self-injurious behaviors (e.g., biting, poking, scratching), and use of repetitive language (Srinivasan et al., 2015). Recording of the absence of sharing included seven behaviors, four of which were sensori-motor play, mannerisms, ritual, and aggression (Duquette et al., 2008). Finally, non-standardized measurements included an interview with with parents and assessment of the children's autistic behaviors by a psychologist pre- and post-intervention (Taheri et al., 2018).

3.3.6 Research design

The studies included in the review used a wide variety of research designs. Three studies used a single case design (David et al., 2020; Duquette et al., 2008; Taheri et al., 2018). One was a pilot study (Shamsuddin et al., 2013), one was a case study (Shamsuddin et al., 2012), one used observation methods, pre-post-intervention, without a control group (Taheri et al., 2021), and one followed a randomized controlled trial design (Srinivasan et al., 2015). In three studies the research design was not specified, but comparison was made between two set-ups, one with the robot and one with a human (Costa et al., 2018; Ismail et al., 2012) or one with the robotic dog and one with a toy dog (Stanton et al., 2008).

3.3.7 Intervention outcomes

All intervention outcomes are reported in Table 2. In most studies, the researchers observed that participants in the robot sessions engaged in fewer repetitive or stereotyped behaviors (Costa et al., 2018; Duquette et al., 2008; Stanton et al., 2008) and showed reduced repetitive play with their favorite toy (Duquette et al., 2008). In one study, reduction in stereotyped behavior in REI was demonstrated by 5 of the 6 children (Ismail et al., 2012). Only one study found that REI led to some increase in RSBs in the children with ASD (David et al., 2020) and one showed no training-related change (Srinivasan et al., 2015).

Ismail et al. (2012) investigated the relationship between RSBs and the intelligence level of children with ASD in two set-ups and observed that children with higher IQ scores manifested less stereotyped behavior in REI than in the normal classroom session with the human partner. Shamsuddin et al. (2012) concluded that children with ASD with average to above average IQ will be receptive to robot-based intervention even in the first interaction session. Shamsuddin et al. (2013) analyzed the stereotyped behaviors of ASD children with lower IQ level, in three categories based on IQ scores: moderate (40-54), mildly (55-69), and borderline impaired (70-79). Their results showed reduction in RSBs in five of the six participants, but a clear distinction could not be drawn between the three low IQ groups in the response to the robot.

Table 2. Summary of the characteristics of REIs and RSBs in children with ASD.

Authors, Country	Participants: number (n), gender (m, f), mean age (M), diagnosis	IQ	Robot	Context	Duration	Training	Type of measurement	Research Design	Outcomes
Costa et al., 2018 Luxembourg	n=15m 4-14 years M=9.37 ASD	<80 (n=8) 80-120 (n=6) >120 (n=1)	Humanoid robot QTrobot	Institutions for children with ASD	1 2-h long session	Story telling & imitation game	(video observation) Number of chains of RSBs was counted	Comparison of scores between 2 set-ups, robot & human	Children engaged in fewer RSBs with the robot than with the human
David et al., 2020 Romania	n=5 (3m, 2f) 3-5 years M=4.6 ASD	Nm	Humanoid robot Nao	Experimental room in autism center	1 5´-15´ session per day, (total 20 sessions)	Turn-taking task on a touchscreen device	(video observation) Frequency of stereotyped behaviors (repetitive or ritualistic movement, posture or utterances)	Single case alternative treatments design	REI led to some increases in stereotyped behaviors
Duquette et al., 2008 Canada	n=4 (3m, 1f) 4-5 years M=5 LF-ASD	Nm	Humanoid robot Tito	Experimental (5.5m x 3.3m) room	3 weeklies sessions for 7 weeks, (total 21 sessions)	Imitative play (facial expressions, body movements & familiar actions with or without objects)	(video footage observation) Evaluation sheets for presence or absence of the variable "Absence of sharing" which includes repetitive sensori-motor play, mannerisms, ritual & aggression	Single case protocol ABA/AB' A model	Children showed reduced repetitive plays with their favorite toy & no repetitive or stereotyped behavior toward the robot
Ismail et al., 2012 Malaysia	n=6 (Nm) years=Nm M=Nm ASD	44-107 M=73,83	Humanoid robot Nao	Room in National Autism Society of Malaysia (NASOM)	1 session 14´& 30´´ for 5 modules excluding the 30´´ break	Simple modules of interaction by the robot (verbal communications [M2], simple physical actions [M 1,3,5] & interesting	Behavior score sheet under the GARS-2 Subscale of Stereotyped Behavior (8 items)	Comparison of scores between 2 set-ups, robot & human	Reduced stereotyped behavior in REI for 5 of the 6 children

						sounds [M4])			
Shamsuddin et al., 2012 Malaysia	n=10m 10 years HF-ASD	107	Humanoid robot Nao	Room in NASOM center	1 session 14´& 30´´ for 5 modules excluding the 30´´ break	Simple modules of interaction by the robot (verbal communications [M2], simple physical actions [M 1,3,5] & interesting sounds [M4])	Behavior score sheet under the GARS-2 Subscale for Stereotyped Behavior (8 items)	Case study, comparison of scores between 2 set-ups, REI & typical class session	Stereotyped behavior of the child became less evident during the REI
Shamsuddin et al., 2013 Malaysia	n=6 (5m, 1f) 5-13 years M=8.9 LF-ASD	46-78 M=63	Humanoid robot Nao	Room in NASOM center	1 session 14´ & 30´´ for 5 modules excluding the 30´´ break	Simple modules of interaction by the robot (verbal communications [M2], simple physical actions [M 1,3,5] & interesting sounds [M4])	Behavior score sheet under the GARS-2 Subscale for Stereotyped Behavior (8 items)	Pilot study, comparison of scores between 2 set-ups, REI & typical class session	Reduced percentage in stereotyped behavior during the REI
Srinivasan et al., 2015 USA	n=36 (32m, 4f) 5-12 years M=7.58 (RG: 10m, 2f, M=7.88 RoG: 11m, 1f, M=7.52 CG: 11m, 1f, M=7.36) ASD	Nm	Humanoid robot Nao & mobile robot Rovio™	Home sessions	4 weeklies 45´sessions for 8 weeks, (total 32 sessions)	Training involving imitation and interpersonal synchrony-based games	(video observation) Frequencies in standard time of repetitive behaviors: 1) Sensory behaviors (repetitive movements with objects) 2) Negative behaviors (SIB, use of repetitive language) 3) Stereotyped behaviors (repetitive movements of the body)	Randomized controlled trial design	No training-related changes in repetitive behaviors in REI
Stanton et al., 2008 USA	n=11 (10m, 1f) 5-8 years M=Nm ASD	Nm	The robotic dog AIBO	Experimental room	1 30´ session	Behavioral interactions with the robot (e.g., holding it and rolling the ball to it)	(video observation) Frequency of occurrence of autistic behaviors (GARS, 16 behaviors)	Comparison of scores between 2 set-ups, toy dog & robotic dog	The children engaged in fewer autistic behaviors in the robot session
Taheri et al., 2018 Iran	n=2m (twins) 7 years HF- & LF-ASD	Nm	Humanoid robot Nao & Alice-R50	Social & Cognitive Robotics Lab at Sharif University of Technology (in a 5x5x3m^3 room)	12 30´ sessions	Therapeutic games targeting different cognitive skills, imitation, joint attention, social skills, eye-contact & turn-taking	1) GARS (Stereotyped Behaviors subscale) 2) Content analysis of video records 3) Psychologist's assessment of behaviors 4) Interview with parents	Single subject design	Stereotyped behaviors of LF-ASD subject decreased during the REI
Taheri et al., 2021 Iran	n=4 (3m, 1f) 5-6 years M=5.8 LF-ASD	Nm	Humanoid robot Nao	Social & Cognitive Robotics Lab at Sharif University of Technology (in a 3.5x4.5x3 m^3 room)	13 20´-30´ sessions	Imitation, joint attention & turn-taking music-based games	GARS (Stereotyped Behaviors subscale)	Pre-, Post-comparison, without control group	Stereotyped behaviors of LF participants decreased (large Cohen's d effect size)
HF= high functioning, LF= low functioning, RG = Rhythm Group, RoG= Robot Group, CG= Comparison Group, Nm= Not mentioned									

Source: Authors.

4. Discussion

The literature review resulted in 10 papers that met the inclusion criteria. The age of the total of 99 participants was 3 to 14 years, mean 7.27 years, with a male/female ratio of about 9:1, which is unsurprising, as ASD is more commonly diagnosed in males (Loomes et al., 2017). The sample size in most of the studies was small, ranging from 2 to 36, and widely differing study designs were used. The studies took place in six countries on three continents which is a clear indication of the worldwide research interest in studying the effect of REIs on the RSBs of children with ASD.

The studies used six different robots, most of which were anthropomorphic, that can be explained by the activities that researchers used to achieve the intended behavioral goals. Anthropomorphic robots are documented to be more effective in teaching specific social and communication skills, such as imitation, turn-taking, and joint attention (Cabibihan et al., 2013; Scassellati et al., 2012; Shamsuddin et al., 2013; Taheri et al., 2015). They also exhibit a more complex expression, which, on the one hand, keeps children focused on the activity for a longer time and, on the other hand, favors generalization of behaviors in children with ASD (Cabibihan et al., 2013; Ricks & Colton, 2010; Scassellati et al, 2012). The intervention programs varied in the length, duration, number of sessions, measurements used, and training. The intervention sessions ranged from 4.3 minutes (Costa et al., 2018) to 45 minutes (Srinivasan et al., 2015), and the study duration ranged from a single session (Costa et al., 2018; Ismail et al., 2012; Shamsuddin et al., 2012; Shamsuddin et al., 2013; Stanton et al., 2008) to 32 sessions over 8 weeks (Srinivasan et al., 2015). The two studies that recorded an increase (David et al., 2020) or no training-related changes in RSBs (Srinivasan et al., 2015) were those that conducted a large number of sessions (20 and 32 respectively).

The studies used a variety of standardized and non-standardized measurements to evaluate the effect of REIs on RSBs of individuals with ASD. Regarding the type of training, in most studies the researchers used imitation games (Costa et al., 2018; Srinivasan et al., 2015; Taheri et al., 2018; Taheri et al., 2021). Imitation is used in therapy to promote better body awareness, sense of self, and coordination (Costa et al., 2018). Imitation activities can help children with ASD to realize that their actions are observed by the people around them, which is likely to lead to a reduction in their RSBs (Shamsuddin et al., 2013). They also used turn-taking games (Taheri et al., 2018; Taheri et al., 2021; David et al., 2020) and music-based games (Taheri et al., 2021; Srinivasan et al., 2015). Music therapy can be effective in the treatment program of individuals with ASD (Taheri et al., 2021) and has been used to promote their social communication, motor, and behavioral skills (Bharathi et al., 2019; Finnigan & Starr, 2010; LaGasse & Hardy, 2013; Srinivasan et al., 2015). Music-based training provides a safe and enjoyable environment that allows the children to explore their surroundings and express their potential (Srinivasan et al., 2015). Robot assisted music-based sessions have been shown to result in reduction of RSBs in children with ASD (Taheri et al., 2019; Taheri et al., 2021).

Regarding the role of the REIs in the reduction of RSBs of children with ASD, in most of the studies the participants in the robot sessions engaged in fewer RSBs (Costa et al., 2018; Duquette et al., 2008; Stanton et al., 2008); only in one the REI led to an increase in RSBs (David et al., 2020) and in one no training-related change was observed (Srinivasan et al., 2015). This may be due to the technical limitations of the robot that made the context less compelling than the other training contexts, or may be related to the intervention activities used by the researchers. The training program involving imitation games requiring rapid body movements that simulate natural movement may be more effective when presented by the human partner, because the robot is much slower and its responses slightly delayed (Srinivasan et al., 2015).

The few studies that took into account the IQ scores showed that the children with ASD who had higher IQ scores accepted REI from the very first moment of contact, and exhibited less RSBs than in human-based interaction (Ismail et al., 2012; Shamsuddin et al., 2012). A clear pattern could not be drawn to describe and distinguish between children at different lower IQ levels (Shamsuddin et al., 2013). In order this phenomenon to be clarified it will be necessary to conduct studies with

larger samples of children with ASD, comparing those with lower-level and higher-level IQ (Shamsuddin et al., 2013). Regarding the level of functionality of the participants in the studies, Taheri et al. (2018) conducted a REI with two fraternal twins with ASD, one high-functioning and the other low-functioning, and observed that the low-functioning twin showed fewer RSBs, which can be explained by the level of cognitive skills. Interventions aimed at low-level cognitive skills are more effective in low-functioning individuals, as in high-functioning subjects, the interventions have no further effect above a particular level (Taheri et al., 2018).

This review provides early research evidence on the use of REIs for RSBs in 3-14-year-old children with ASD. Several limitations should be mentioned, the main of which is the small number of studies, and the data extraction based on this limited number restricts the generalization of the review findings. Most of the studies were of small samples of children and the results were based on a limited number of intervention sessions. Additionally, the search was limited to studies published in English. The studies were diverse, with wide variation in the methods and the measurements of RSBs, which affected the ability to carry out comparisons between the studies. Finally, the selection of the articles, which presented positive results about the effectiveness of REIs in RSBs exhibited by the participants, may be viewed as subjective and this may also be considered as a limitation of the current review.

To conclude, based on this scoping review, further investigation needs to be carried out to verify the effects of the REIs in this population. It would be helpful to conduct a review including studies published in languages other than English to provide an overall picture from different cultural contexts. More meticulously controlled studies with larger samples of children and clear definition of their pre-intervention characteristics, including IQ level, will be necessary to derive clearer results. Future research could investigate the current research questions and include more accurate data analysis, combining quantitative and qualitative analysis. A vast majority of studies included in the review were conducted in experimental rooms, and there is a need to move such research interventions into other settings, such as the home, school and community settings, where the children manifest RSBs also.

5. Conclusion

This scoping review explored the current evidence on the role of REIs on RSBs in children with ASD. RSBs constitute a core symptom in children with ASD, and can have a detrimental effect on their functionality. REIs have the potential to improve various behaviors in children with ASD.

Based on the few relevant studies identified here, despite the methodological diversity, REIs are promising to identify positive outcomes in respect of RSBs. Further studies with more rigorous design, and with larger more representative samples need to be conducted, to provide a clear picture of the effects of REIs on RSBs in children with ASD.

Moreover, there is a need to move such research interventions into other settings, such as the home, school and community settings, where the children manifest RSBs also.

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