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Serap Doğan & Aysun Çolak

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REVIEW ARTICLE

Social robots in the instruction of social skills in autism: a comprehensive descriptive analysis of single-case experimental designs

Serap Doğan[a] and Aysun Çolak[b]

[a]Department of Special Education, Faculty of Education, Gaziantep University, Gaziantep, Turkey; [b]Department of Special Education, Faculty of Education, Anadolu University, Eskisehir, Turkey

ABSTRACT

Purpose: The rapid technological advances, the traits of individuals with ASD and their interest in technology are promising for the instruction of social skills to individuals with autism spectrum disorder (ASD) using various technological interventions. Robotic interventions are among these. However, although robotics is frequently used with individuals with ASD, there is a limited number of reviews on social skills instruction and methods. The present study aimed to conduct a comprehensive descriptive analysis on single-case experimental designs where social skills were instructed to individuals with ASD and social robots were included as independent variables.
Materials and methods: Thirteen single-case experimental designs published in peer-reviewed journals in which social skills were taught to individuals with ASD using social robots were reviewed with a comprehensive descriptive analysis based on five categories: (a) key characteristics, (b) methodological characteristics, (c) findings, (d) data analysis, and (e) key parameters in single-case experimental designs.
Results: Social robots are generally effective in the instruction of social skills. Several social skills (e.g., making eye contact, social interaction, simple greetings) were instructed in the studies. Humanoid robots and NAO were used generally. The study data were predominantly analyzed statistically. There were several problems in research based on the basic parameters in single-case experimental designs.
Conclusions: The researches in this study differ in several respects (e.g., results, data analysis, and dependent variable). Thus, there is still a need for several robotics studies in the instruction of social skills.

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Robot; social robots; autism spectrum disorders; social skills; human-robot interaction

➤ IMPLICATIONS FOR REHABILITATION

- This study will be a guide for teachers who currently use robots in their classrooms but do not know which skills to use in teaching and how to use them functionally, as it shows applied research with robots.
- The findings of this research will show implementers working with children with ASD that technological tools can be used in rehabilitation environments, and that teachers can take a place in their robots in interventions for children with ASD, giving them a different perspective.
- It will be seen that the education of children with ASD is not only 1:1 and with humans, but robots can also provide education. In this way, the power of technology in teaching will become clearer. Especially in rehabilitation.
- Finally, this research will offer new options in teaching especially for teachers who aim at teaching social skills and will give them the opportunity to comprehensively examine the processes of different studies on these subjects.

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder the symptoms of which are initially observed in childhood and continue throughout life [1]. According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) published by the APA, individuals with ASD experience significant challenges in social skills. Social skills are socially acceptable, learned behaviour [2] that allows the individuals to elicit positive and avoid negative reactions in their interactions with Gresham and Elliott [3]. Despite the presence of a common definition for social skills, it could be observed that these skills are classified in various categories in research [4]. Sargent et al. [5] categorized social skills into various groups, such as initiating interaction (e.g., initiating a conversation), reaction (e.g., expression of a complaint), personal social skills (e.g., coping with embarrassment and negative emotions), domestic, and scholar and communal social skills and behaviours (e.g., waiting in line, getting on the school bus based on certain rules), and argued that there could be hundreds of social skills. According to Grossard et al. [6], although social skills include verbal (lingual, speech, tone of voice, etc.) and non-verbal (eye contact, facial expressions, gestures, etc.) skills, more than one social skill is required to achieve complex social goals, such as initiating and maintaining context-adequate communication.

CONTACT Serap Doğan serapdogan@anadolu.edu.tr Department of Special Education, Faculty of Education, Gaziantep University, Gaziantep, Turkey

Social skills may differ based on the current situation and environment.

Social skills are extremely important skills that allow individuals to (a) interact with their environment, (b) adapt to the environment, (c) function in the environment [7], and (d) participate in social activities [7,8]. Individuals with low social skills experience difficulties in independent living, employment [9], and establishing meaningful social interactions with others [10–13]. Furthermore, previous study findings demonstrated that inadequate social skills could lead to (a) rejection by peers at school-age [14], (b) low academic achievement, and (c) problems, such as stress and anxiety in later developmental stages [15]. Because social skills are important and necessary for people with ASD, multiple studies have been conducted to explore the efficiency of various social skill education techniques for these people [e.g., 16–24]. It could be observed that various evidence-based practices (EBP), such as video models and reaction cue methods were employed in the instruction of social skills, such as social interaction [19], coping with inadequate peer reactions [22], work-related demands and providing appropriate verbal responses to the staff, establishing communications [17], verbal or non-verbal requests [21], verbal requests [25], joint attention [26], greeting and starting a conversation [20], greeting, expressing needs and emotions, asking permission [23], recognizing and participating in an activity [24], greeting and farewell gestures [16], asking spontaneous questions, initiating interaction, and responding [18] in these studies.

The instruction of the target skill/behaviour with proven methods is desired, recommended, and a necessary approach in scientific research. EBP are instructions and sets of procedures that allow researchers to show that the practice results in positive outcomes for children, adolescents, and adults with ASD [27]. EBP provides the greatest value in areas, such as science, economics, ethics, and productivity. However, a review of the literature indicated that, while EBP was utilized in the education of social skills to individuals with ASD, other methods whose usefulness had not been established were also used (e.g., robotics, augmented reality).

Autism and social robots

Technological improvements, particularly in the twenty-first century, have resulted in the widespread use of technological instruments in education [28]. The adoption of technological tools by several fields, including health, arts, and education led to a different approach to the development of practices for individuals with ASD [29]. Technological developments also led to several studies conducted with various tools, such as speech generating devices [30,31], augmented reality [32,33], and computer games in the education of individuals with ASD. Technological discoveries and innovations, particularly in the recent decade, have led to advancements in robotics [34].

Robots, in general, are utilized for industrial automation methods that have programmable elements on three or more axes and are automatic, reprogrammable, portable, or fixed devices [35]. Even though the preceding definition highlights the use of robots in industrial processes, robots are widely used in rehabilitation, regulation of physical stimuli, education of adults with cognitive disorders, and individuals with disabilities [36]. In the previous decade, robotics has undergone substantial changes and begun to penetrate industries, such as entertainment, transportation, health, and rehabilitation through direct human-robot interaction [37]. Due to these developments, robots have been employed in the treatment and education of individuals with ASD since the mid-2000s [38]. High technology use and advances in artificial intelligence have increased the number of studies on social robots [39]. Furthermore, social robots are employed in research due to the interest of individuals with ASD in technology [40]. According to social motivation theory, when people are motivated, they can learn faster and behave more appropriately and adaptively. In addition, they can achieve the desired goals more smoothly. For this reason, motivation and motivators are very important for individuals with autism, as it is for all individuals. Technological tools are important to ensure the social motivation of children with autism. Intense world theory is important as well as social motivation theory. The intense world theory explains that core cognitive consequences in children with autism spectrum disorder are hyper-perception, hyper-attention, hyper-memory, and hyper-emotionality. For this reason, technological tools that can activate this function are important for the higher function of children with autism.

Social robots are a subfield in robotics [39]. These are robots designed to reveal the social behaviour and perceptions of individuals they interact [41]. According to another definition, social robots are autonomous or semi-autonomous devices that interact and communicate with individuals and monitor their behaviour [42]. Thus, it could be suggested that social robots are not passive participants in the environment, but rather instruments that allow the individuals they interact with to exhibit certain behaviour [41]. Social robots exhibit behaviours similar to humans. In other words, they interact and communicate with individuals based on several social rules similar to interhuman communications *via* speech, facial expressions, and body language [43]. According to reports, the number of social robots has expanded over the years, and these robots vary in price, design, and appearance [44]. These variances are due to the researchers' intention to evaluate the interaction between people with ASD and various robots to determine the most effective and efficient [45,46]. Individuals with ASD were taught to use social robots with instructions for imitation [47], adequate emotional responses [48], fruit salad preparation [49], gaming skills [50], reverse learning [51], and various social skills, such as making requests, joint attention, social interaction, asking independent questions, demanding, initiating communication, and interacting with peers [16,18,45,52–60]. Apart from applied research, various systematic reviews that investigated the employment of social robots with individuals with ASD were conducted [34,40,61–64].

Systematic literature reviews

Diehl et al. [40] compared two interventions with robots/robot-like tools, and non-robots to determine whether there was experimental evidence for the clinical use of robots in the diagnosis and education of individuals with ASD in experimental studies published in peer-reviewed journals or conference publications up to 2011. They analyzed 15 studies based on five variables: author-year of publication, number of participants/diagnosis/age, comparison phases in the experimental research, and method and findings with the descriptive approach. The findings suggested that the studies should be supported by further research since most were initial studies on the clinical use of the robots and methodological limitations. Due to these reasons, previous studies could not reach clear conclusions on the clinical use of robots. In a systematic review [61], between 1990 and 2014, 22 experimental and quasi-experimental articles were published in peer-reviewed journals on the interaction between individuals with ASD and robots were examined, based on six variables and guidelines published by significant institutions, centres, and researchers on EBP in ASD (e.g., National Professional Autism Centre [NAC], National Professional Development Centre [NPDC]). In the study, ASD and robot interaction was described as the improvement in any characteristic in the behaviour of at least one individual with ASD by the robot (e.g., learning life skills or reduction in undesirable behaviour). This study differed from others in that it conducted a full descriptive analysis based on the principles and recommendations of EBP in ASD. The findings reported in the studies on human-robot interaction varied, and certain studies reported positive findings in EBP. Pennisi et al. [34] aimed to determine whether social robots could be used in autism therapy and examined studies conducted between 2004 and 2014 in which robots were used in diagnosis, evaluation, or treatment, and at least one intervention, such as an experiment, pilot scheme, or trial was carried out, that were based on eight variables. The study's findings showed positive outcomes in the usage of social robots as a therapeutic tool in the education of people with ASD. Toh et al. [28] reviewed 27 non-experimental (mixed, longitudinal, relational, and case studies) and quasi-experimental (pre-test/post-test) studies published between 2003 and 2013 on children with early childhood or earlier ASD. The studies were analyzed based on four variables: the type of research, the effect of robots on child behaviour or development, the perceptions of stakeholders about robots, and the interactions of the children about the appearance and design of the robot. The findings demonstrated that robots had an impact on several traits of the children (language, cognition, concept acquisition, and social skills), parental perceptions about the children with ASD and the appearance of the robots improved, and children interacted with robots without any problems. In a study conducted by Saleh et al. [64], peer-reviewed articles in which robots were used in the diagnosis, evaluation, or rehabilitation of individuals with ASD were indexed in three databases between 2008 and 2017. The studies were thoroughly examined based on the type of robot, participants, study aims and methodology, and findings. The findings revealed that robots were used to improve the learning of children with ASD, determine the applicability and validity of the robots, and improve social communication skills and reduce stereotypical behaviour. Lambert et al. [65] reviewed the studies conducted with social robots between 2008 and 2018 based on (a) practice areas, basic research titles, publication information, intended use, and the capabilities of the social robot. It was demonstrated that the studies analyzed individuals' expectations of social robots, and their perceptions about robot interaction and the studies aimed to increase the employment of robots in education.

There is only one systematic review [63] where social robots were investigated in social skills instruction. Thirty-nine papers published in peer-reviewed journals indexed in the Psych Info and Scopus databases between 2010 and 2019 on persons diagnosed with ASD in at least one experimental and/or pilot phase were included in the analysis. The studies were included in the review based on certain criteria, such as the presence of at least one experimental process, testing the effectiveness or efficiency of social robots, and the measurement of social skills based on social interaction and communication (imitation, taking turns, initiating interaction, recognizing facial expressions, game play, etc.). The findings demonstrated that social robots improved the social skills of individuals with ASD, and mostly the ability to make eye contact was studied.

There are several differences between the present study and the study by Damianidou et al. [63]. These differences include the following: (a) Damianidou et al. [63] reviewed studies indexed in two databases and conducted between 2010 and 2019. The present study had no limitation on the year of publication and the studies indexed in the Academic Search Complete, ERIC, Ebscohost, IEEE Xplore, MEDLINE, Science Direct, Scopus, and Psycinfo databases were reviewed. The references in the articles were examined, and the journals with the greatest number of studies on social robots were also reviewed. Thus, it was possible for [63] to review several studies not indexed in the databases. (b) Damianidou et al. [63] included the skills that could be measured with social interaction and communication in their social skills set. In the present study, the intervention process of the studies were reviewed and the authors decided whether the target skill was a social skill or not. Thus, the selection was based on target skill topography instead of a measurement limit. (c) Damianidou et al. [63] determined that all reviewed study participants should be individuals with ASD in at least one implementation phase. In the present study, at least one participant with a diagnosis of ASD was sufficient for inclusion. It was suggested that this criterion would lead to the review of a higher number of studies. (d) Unlike the variables analyzed by Damianidou et al. [63], in the present study, at least 10 variables, such as settings, implementer, measurement and criterion of the dependent variable, time of the intervention, participant evaluation tools, scores, social validity, and limitations of the study were determined. Furthermore, the studies were reviewed in detail based on basic features, methodology, and findings. (e) Finally, the most important differences between the present study and previous systematic reviews, especially the study by Damianidou et al. [63] included the review of the data analysis, only descriptive analysis of the single-case experimental designs (SCED), as well as the analysis of SCED selected by the pioneering researchers in the field based on basic parameters in these studies (e.g., baseline and intervention phase, internal and external validity, prediction-verification-replication, functional relationship).

It is known that the employment of social robots outside of scientific research has increased in the last decade and their use has been functional in various fields due to commercial and technological advances [65]. One of these areas was education [66] and especially special education [67,68]. Social robots arose as a new therapeutic tool in the instruction of social skills to individuals with ASD as a result of the rapid advancement of robotics programming in special education [38]. Determination of the therapeutic impact of social robots on individuals with ASD who experience difficulties in social skills is only possible through the comprehensive analysis of several studies on the instruction of these skills. The fact that there is only one systematic review in the literature leads to a requirement for further reviews.

Social robots are employed for different purposes and various interventions are conducted with robots in the education of individuals with ASD. However, the most efficient robots are yet to be determined due to the lack of evidence on the effectiveness of these practices and the heterogeneity of the individuals in the spectrum [34,61]. This ambiguity about robots (lack of evidence) may lead to several questions in various disciplines and implementers (teachers, researchers, therapists, etc.) about the field of robotics and instruction with robots (e.g., Are social robots effective? Can we use social robots in the instruction of social skills?). A comprehensive analysis of research on social skills instruction could further clarify the robotics literature. The reports in the literature suggest that robots were generally effective and promising in the instruction of social skills to individuals with ASD. However, it is also known that comprehensive reviews could explain this effect in detail. Thus, it is important to conduct comprehensive reviews to fill the gap in the robotics literature and reveal the effects of the interventions conducted with robots [61].

There are different reviews as mentioned above. However, there is only one study [63] where social robots were employed in social skills instruction. Furthermore, given that (a) social skills are one of the most difficult skill areas in ASD, (b) social robot research primarily focussed on social skill instruction, and (c) social robots were presented as an alternative to interhuman interaction [69], it was surprising that social skills instruction was researched in only one study. Thus, there is a need for research and comprehensive analyses on social robot studies based on various variables (aim, intervention, findings, limitations, etc.).

Finally, practically all systematic reviews of research were found to be based on basic characteristics (Participants, robot types, dependent variable, etc.). There is a study where social robot research was analyzed based on two research designs (group experimental and single-case experimental designs) [61]. In the study, SCEDs were analyzed based on four basic parameters: baseline, experimental control, presentation of findings, and reliability. In group experimental studies consisting of at least two groups of participants, there is a treatment or intervention performed with a social robot in a group. In these studies, the results of the treatment group with robots are generally positive, but the results of all group experimental studies show variability.

However, since SCED is still one of the most popular designs in autism research [70] and it is one of the two most preferred research designs in robotics studies [61], SCED is the mainstay of research features that should be considered in this field. Furthermore, a detailed investigation of the research design in robotics studies, the effectiveness of which is yet to be proven, and has reported uncertain findings could improve the quality of future research and systematize the planning and implementation of SCED. This issue could be resolved by the review of robotics research based on basic parameters in SCED.

Thus, the present study aimed to conduct a comprehensive descriptive analysis of SCED on the instruction of social skills to individuals with ASD by social robots. For this purpose, the following research problems were determined:

1. What are the main characteristics (country of study, year of study, number of participants, diagnosis, age, gender, diagnostic tool, demographics, settings, instructional approach, aim) of the reviewed studies?
2. What are the methodological characteristics (research model, implementer, definition, measurement, criterion-dependent variable, independent variable, name, type of social robot, and duration of intervention) of the reviewed studies?
3. What are the characteristics of the reviewed study findings (the result of the study, reliability, generalization, follow-up, social validity, limitations)?
4. Which data analysis methods were adopted in the reviewed studies?
5. What were the basic single-case experimental design parameters (prediction-verification-replication, baseline and intervention phase, dependent and independent variables, functional relationship, internal validity, external validity)?

Materials and methods

The review process

A comprehensive descriptive analysis was conducted on studies where social skills were instructed to individuals with ASD with social robots. Since the first robot was used in the education of individuals with ASD in a study by Weir and Emanuel [71], the year of publication was not limited in the review. A digital search was conducted on eight databases. The keywords listed in Table 1 were searched in Academic Search Complete, ERIC, Ebscohost, IEEE Xplore, MEDLINE, Science Direct, Scopus, and Psycinfo databases without any year restriction, and the language was limited to the publications in English, "academic journals" were selected as the publication, and the "deselect extended content" ticker was selected. The last search was conducted on 4 April 2021. To ensure all available articles are accessed in the digital search, the references listed in the 60 articles accessed in the first search were reviewed and a second search was conducted, and 10 further articles were accessed. The titles and abstracts of these 10 articles were read, and they were not included in the analysis since the target skill and selected methods were inadequate in these papers.

The searches revealed 10,038 articles. These were saved in an EndNote X9 software folder. The search flowchart is presented in Figure 1.

Inclusion and exclusion criteria

Certain criteria were established for the research to be included in the complete descriptive analysis. These criteria are listed in Table 1. Exclusion criteria were as follows: (a) designed with a model other than SCED (e.g., case study, control group design), (b) publication language other than English, (c) the lack of at least one participant with ASD, (d) lack of at least one social skill, (e) instruction of social

Table 1. Inclusion criteria and research strategy.

Criterion	Inclusion criterion	Keywords[a]
Participant	At least one participant with ASD/PDD/PDD-NOD diagnosis	1. "autis* OR autism" OR "asd" OR "autism spectrum disorders" OR "PDD" OR "PDD-NOS"
Year of publication	Up to 2021	
Independent variable/ (application/intervention)	Instruction of at least one social skill with only social robot/testing the effectiveness/efficiency of social robot in social skill instruction	2. "sociable robots" OR "social robots" OR "therapeutic robots" OR "socially assistive robots" OR "social robots" OR "therapeutic robots" OR "socially assistive robots" OR "robot technology" OR "human robot interaction"
Method	Reporting the employment of a single-subject experimental research design (i.e., ABA, alternating applications)	3. "single case experimental design" OR "single subject design" OR "1 case design" OR "withdrawal design" OR "reversal design" OR "AB design" OR "ABA design" OR "ABAB design" OR "multiple baseline design" OR "multiple treatment design" OR "multiple probe design" OR "alternating treatments design"
Dependent variable/target skill	At least one target social skill	4. "social skills" OR "social skills intervention" OR "social skills training"
Language	English	
Publisher	Peer-reviewed scientific journal	

[a]The search was conducted with the AND limiter between the keywords.

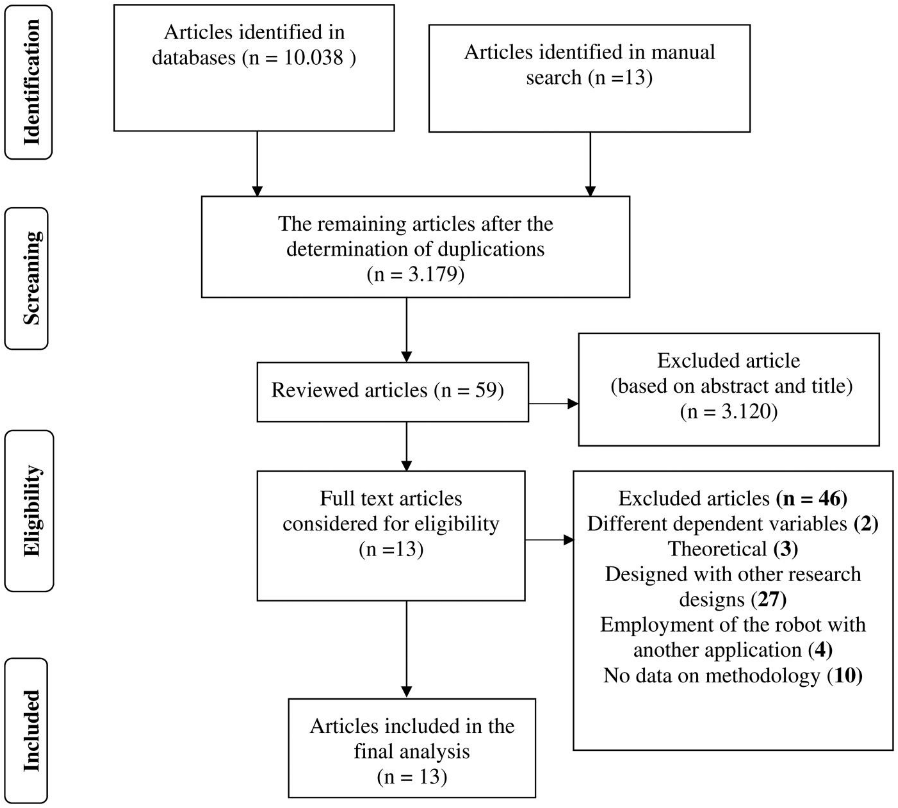


Figure 1. The research flowchart.

skills without social robots, (f) employment of social robots as evaluators, assistive tools, implementer assistants or reinforcers (e.g., teacher assistant, social story narrator), and (g) presence of another intervention along with a social robot (e.g., social robot with LOGO therapy, robots and video modelling, social robot and instruction with discrete trials).

Thirteen studies were included in the comprehensive analysis based on the specified criteria. The analysis was conducted based on 18 variables in three categories and basic characteristics, methods and findings, and the principal parameters in SCED

The basic characteristics were analyzed based on the following variables

(a) Country of study, (b) year of study, (c) participant demographics (count, diagnosis, age, gender, diagnostic tool), (d) setting, (e) instructional setting, and (f) study aim.

Methodological characteristics were analyzed based on the following variables

(a) Research model, (b) implementer, (c) dependent variable (definition, measurement, criterion), (d) independent variable, (e) social robot (name, type), and (f) intervention duration.

The study findings were analyzed based on the following variables

(a) The outcome of the study, (b) reliability, (c) generalization, (d) follow-up, (e) social validity, and (f) limitations.

Reliability was calculated based on the above-mentioned variables. To determine intercoder reliability, at least 30% of the studies ($n = 5$) were determined using an internet-based random number generator website (www.randomiser.org) and submitted to an expert in the field of special education. To conduct the reliability analysis, an intercoder reliability data form was developed. The unbiased assignment studies were analyzed by the observer, and the decisions were noted as yes, no, or details on the form. The intercoder reliability was then determined using the first author's and observer's analysis findings and the inter-coder reliability formula [(agreement)/(agreement + disagreement) $\times$ 100]. The dependability coefficient was calculated to be 96% (range = 91–100%).

As seen in Table 1, it was determined that the study keywords were determined and coded based on the research design, participant, dependent, and independent variables, and the studies were limited by general constrictors (research language, journal of publication, etc.). The studies included in the meta-analysis based on the inclusion and exclusion criteria are presented in Figure 2.

Results

Research issues 1, 2, and 3 are divided into three categories: basic characteristics, methodology, and findings; research problem 4 is based on data analysis; and research problem 5 is based on the basic SCED parameters.

Research question 1: the studies based on basic characteristics

Basic characteristics included six variables: (a) country and (b) year of the research, (c) participant demographics (count, diagnosis, age, gender, diagnostic tool), (d) setting, (e) instructional setting, and (f) aim of the study. Details are presented in the following paragraphs and Table 2.

a. *Country of research:* It was observed that two studies were conducted in the Netherlands, four in Romania, one in Greece, four in Italy, and two were conducted in the UK and Canada.

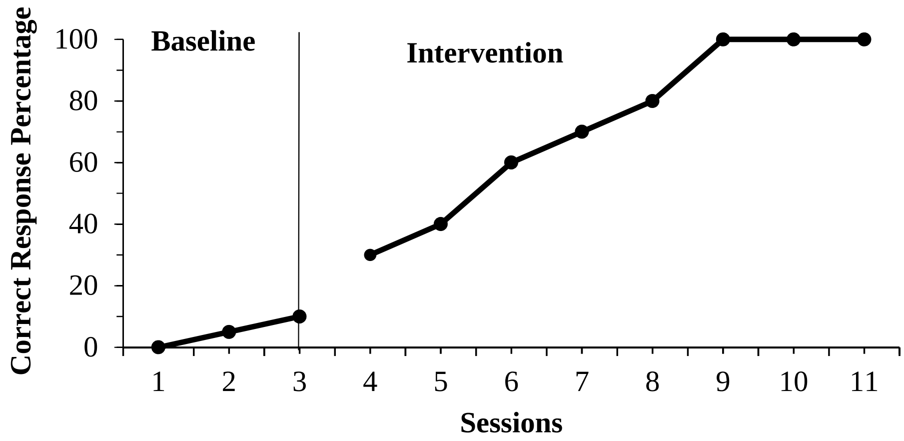


Figure 2. A sample single-case experimental design graphic.

b. *Year of research:* It was determined that two studies were conducted in 2013, three in 2018, three in 2020, and one study was conducted in 2008, 2012, 2014, 2017, and 2019.
c. *Participants:* Participants were analyzed based on 5 sub-variables: number, diagnosis, age, gender, and diagnostic tool.

Participant number
It was observed that the participant number varied between 1 and 12 and the overall participant number was 55.

Diagnosis
The studies reported that one participant had speech and language disorder [59], 39 had ASD [e.g., 53,55,57,58,72], 12 had autism [e.g., 46,59,60] and three had pervasive developmental disorder [18].

Age
Participant age varied between 4 and 12. In five studies, the participants were at pre-school age (3–6 years old) [e.g., 16,46,54,59], while in eight, they were school-age children (6–12 years) [e.g., 18,57,60,73].

Gender
Forty-five participants were male, and 10 were female.

Diagnostic tools
Thirteen studies revealed the employed diagnostic tools. Certain studies utilized more than one diagnostic tool [e.g., 16,55,46,72,73], while others employed a single diagnostic tool [e.g., 59,60], and one study did not specify the diagnostic tool [56]. Diagnostic tools were employed to measure intelligence [57], autism symptoms [e.g., 46,52,55], motor skills [e.g., 46], adaptive behaviour [e.g., 54,55], to identify various skills [73], and to measure social reactions [72]. Detailed information on diagnostic tools is presented in Table 2.

a. *Setting:* Ten studies were conducted in a therapy room [e.g., 52,55,59,60,72], two were conducted in classroom [54,56], and one was conducted at home [73].
b. *Instruction arrangement:* Nine studies were conducted one-on-one [e.g., 53,57,72], three were conducted with dyadic and triadic interaction [18,59,73], and one was conducted with a small group [56].
c. *Study aim:* The studies aimed to improve skills, such as social interaction behaviour [e.g., 46,57,59,60], joint attention [52,73], spontaneous questions [18], engagement and participation in activities [54], language and communication [16], recognition of facial expressions [72], and social interaction with peers and adults [56].

Research question 2: studies based on methodological characteristics

The methodological characteristics included six variables: (a) research model, (b) implementer, (c) dependent variable (definition, measurement, criterion), (d) independent variable, (e) social robot (name, type, visual), and (f) intervention. Information on the variables is presented in the following paragraphs and Table 3.

a. *Research model:* It was observed that 12 studies tested the impact of the independent variable on the dependent variable [e.g., 16,59,72,73], and one was a comparative study that investigated the impact of two independent variables on the dependent variable [52].
b. *Implementer:* In all investigations, at least one phase was carried out with a robot and individuals. Seven implementers were child psychologists [18], therapists [52], child and adolescent mental health institution instructors [55], and teachers [16,54,57], while no information was supplied on the above-mentioned four [e.g., 59,60]. Robot implementers included several social robots.
c. *Dependent variable:* This section includes three variables: the definition, measurement, and criterion of the dependent variable:

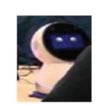
The definition of the dependent variable
In the studies, social skills included facial expressions (happy, sad, etc.), body movements (dancing, raising hands, etc.), imitations with an object (showing the door, etc.), and without an object (shaking hands, shaking hands, etc.) [16], only facial expressions [72], social interaction, imitation, eye contact, smiling [59], independently asking contextual questions [18], imitation, focussing attention to others/turning the head, physical interaction/touching [46], social interaction with a partner in the collaborative game [60], imitation (verbal, fine and motor skills), communication (thank you, hello, etc.), language and speech (selecting an object and saying its name) [54], joint attention, looking, looking and pointing at, looking, pointing at and telling [52], focussing joint attention [73] verbal and motor imitation, receptive and

Table 2. Basic characteristics of the studies.

			Participants							
No	Author/year	Country	Number	Diagnosis[a]	Age	Gender	Diagnostic tool	Setting	Instructional setting	Study aim
1.	Duquette et al. (2008)	Canada	4	ASD	4–5	1 F, 3 M	ADOS-G, PEP-R	Therapy room	1:1	Comparison of language and interaction skills of children with ASD in imitation game facilitated by robot TITO and a human
2.	Tapus et al. (2012)	Romania	4	3 ASD 1 DPD	2–8	4 M	CARS	Therapy room	Dyadic and triadic	Comparison of social interaction in motor imitation game conducted by robot NAO and a human
3.	Huskens et al. (2013)	Netherlands	6	2 ASD, 3 PDD, 1 Autism	8–12	6 M	SCQ	Therapy room	Dyadic and triadic	Comparison of robotic and human applications in the instruction of independent questioning skills in children with ASD
4.	Pop et al. (2013)	Romania	2	Autism	5	1 F, 1 M	MIS, CARS, PS	Therapy room	1:1	Comparison of the human-ASD participant and robot Robonova-ASD participant interactions in collaborative video game
5.	Wainer et al. (2014)	UK	6	Autism	6–8	1 F, 5 M	P-scale	Therapy room	1:1	Comparison of the human-ASD participant and robot Kaspar-ASD participant interactions in collaborative video game
6.	Desideri et al. (2017)	Italy	3	ASD	4	3 M	SABS	Classroom	1:1	The effectiveness of robot NAO in the instruction of activity participation behaviour to children with ASD
7.	David et al. (2018)	Romania	5	ASD	3–5	1 F, 4 M	ADOS (SON-R 21/2–7)	Therapy room	1:1	Comparison of the effectiveness of the applications conducted by robot NAO and a human in the instruction of joint attention skill to children with ASD
8.	Desideri et al. (2018)	Italy	2	ASD	4–10	2 M	CARS, Vineland -II	Therapy room	1:1	The impact of robot NAO on social interaction and the acquisition of target skills
9.	Scasellati et al. (2018)	USA	12	ASD	6–12	5 F, 7 M	DAS, ADI-R, ADOS	Home	Triadic	Investigation of autonomic and effective behavioural interventions of robots in non-clinical settings and the impact of the intervention on social communication skills of the children
10.	Conti et al. (2019)	Italy	1	ASD	10	M	ADOS, SRS	Therapy room	1:1	The impact of robot NAO on recognition of facial expressions (angry, happy, sad, shy, fearful)
11.	Fachanditis et al. (2020)	Greece	4	ASD	7–12	4 M	Greek WISC III	Therapy room	1:1	The differences between the social interaction quality (eye contact, physical intimacy and verbal interaction), and instructional participation of children with ASD after the applications conducted by robot DAISY and the teacher
12.	David et al. (2020)	Romania	5	ASD	4–5	3 M, 1 F	ADOS, LF, CS, SIS, PS, SBS	Therapy room	1:1	Instruction of waiting in the line behaviour with game sessions conducted with a social robot
13.	Desideri et al. (2020)	Italy	1	ASD	6	F	N/A	Inclusive classroom	Small group instruction	Improvement of social interaction opportunities of a child with ASD with peers and adults in an inclusive classroom

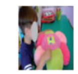
M: male; F: female; ADI-R: autism diagnostic interview-revised; ADOS: autism diagnostic observation schedule; ADOS-G: autism diagnostic observation schedule-generic; CARS: childhood autism rating scale; DAS: differential ability scales; PEP-R: psycho educational profile review; MIS: motor imitation scale; P-scale: performance scale; PS: portage scale; SABS: adaptive behaviour scale-short; SCQ: social communication questionnaire; SON-R 21/2–7: Snijders-Oomen non-verbal intelligence test revised version; SRS: social responsiveness scale; Vineland-II: Vineland adaptive behaviour scale-second edition, WISC III: Wechsler intelligence scale.
[a]Diagnoses are indicated as reported.

Table 3. Methodological characteristics employed in the studies.

			Dependent variable				Social robot			Intervention duration	
Study	Model	Practitioner	Description	Measurement	Criterion	Independent variable	Name	Type	Visual	Session (min)	Total (min)
Duquette et al. (2008)	ABA AB′A	A: educationer B: robot B′: educationer	Facial expressions, body language, imitation game with movements with/without object	Joint attention, response, non-response and imitation skills recorded in discrete trial data form.	N/A	Human and robot	Tito	Portable robot		N/A	N/A
Tapus et al. (2012)	ABAC	A: human B: robot and human C: robot and a different human	Social interaction, imitation, eye contact, smile	Frequency (motor skills with/ without a cue) and time (eye contact with the instructor, smiling/laughing, robot and instructor) were recorded	N/A	Human and robot	Nao	Humanoid robot		A: 5–10 min. B: 5–10, 1, 2–5, 2–5 min C: 1, 2–5, 2–5 min.	N/A
Huskens et al. (2013)	MBM.	B 1: child psychologist Intervention: robot and child psychologist BD 2: child psychologist	Individual questioning within context	Participant reactions within 7 s were recorded.	N/A	Human and robot	Nao	Humanoid robot		B: 5–10 min. I: 10 min.	N/A
Pop et al. (2013)	ABAB	A: human B: robot	Imitation, focussing the attention on the opponent, physical interaction (tactile)	Behaviour frequency was recorded (0 = No, 1 = Yes).	N/A	Robot	Robonova	Humanoid robot		N/A	N/A
Wainer et al. (2014)	ABAB	A: human B: robot	Social interaction with the partner in collaborative game	The presence of six social behaviour was recorded as yes or no.	?	Robot	Kaspar	Humanoid robot		A: 25 min. B: 25 min.	N/A
Desideri et al. (2017)	ABAB	A: educator B: robot	Activities	Sessions were divided into 15 s partial intervals and the observation of the behaviour within this interval was recorded as 1, otherwise as 0.	N/A	Robot	Nao	Humanoid robot		A: 10 min. B: 10 min.	N/A
David et al. (2018)	ATM	BL: therapist Applications: robot and therapist	Joint attention skill (looking, looking + pointing, looking + pointing + telling)	Behavioural grid was employed and scores were recorded (looking within 10 s. "1", looking + pointing "2", pointing "1", none "0", looking + pointing + telling "1" otherwise "0").	?	Human and robot	Nao	Humanoid robot		BL and A: 10 min.	N/A
David et al. (2018)	ATM	BL: therapist Interventions: robot and therapist	Joint attention skill (looking, looking + pointing, looking + pointing + telling)	Behavioural grid was employed and scores were recorded (looking within 10 s. "1", looking + pointing "2", pointing "1", none "0", looking + pointing + telling "1" otherwise "0").	?	Human and robot	Nao	Humanoid robot		BL and A: 10 min.	N/A
Desideri et al. (2018)	ABA′	A and A′: child and adolescent public health institution educator B: robot	Verbal and motor imitation, receptive and expressive language, response to name calling, and verbal request skills	Sessions were divided into 15 s partial intervals and when 4 behaviours were observed 1 point was assigned otherwise 0 point was assigned.	?	Robot	Nao	Humanoid robot		A: 5–15 min. B: 5–15 min.	4 weeks
Scasellati et al. (2018)	ABA	A: robot B: robot A: robot	Social attention skills	Dependent variables were measured with game analysis, daily caregiver survey, and 4-stage clinical assessments.	?	Robot	Jibo	Social robot		First 5 sessions: 27 min. Final 5 sessions: 25 min.	1 month

(*continued*)

Table 3. Continued.

Study	Model	Practitioner	Description	Dependent variable Measurement	Criterion	Independent variable	Social robot Name	Type	Visual	Intervention duration Session (min)	Total (min)
Conti et al. (2019)	ABA′	A: therapist B: robot A′: therapist	Facial expressions (happy, sad, angry, frustrated, scared, neutral/stolid)	Accurate responses. = 1, Inaccurate responses = 0.	?	Robot	NAO	Humanoid robot		A: 10 min. B: 10 min.	5 months
Fachanditis et al. (2020)	ABB′	B: teacher B′: robot	Eye contact, physical intimacy, verbal interaction and speech skills	The frequency of dependent variables of interaction quality	N/A	Human and robot	DAISY	Non-humanoid stuffed toy		A: 5 min B: N/A B′: N/A	Each participant 2 months
David et al. (2020)	ATM	Robot and therapist	Waiting on the line behaviour analyzed with three methods ([1. Social interaction and communication behaviour: eye contact, speech, occupation], [2. Behavioural outcomes: adequate, inadequate, stereotypical behaviour], [3. Emotional outcomes: functional and dysfunctional negative emotions, positive emotions]	Presence of waiting on the line behaviour = 1. The frequency of eye contact, verbal, behavioural and emotional outcomes were recorded.	?	Human and robot	NAO	Humanoid robot		Sessions lasted 5–15 min..	N/A
Desideri et al. (2020)	ABAB	Robot	Social interaction with peers and adults (Non-verbal dual guidance/descriptive adaptation to interaction, self-initiated social occupation, initiation of social interaction, neglect, and happiness)	Dependent variables were measured with descriptive observation of the independent variables.	?	Robot	RoBò	Humanoid robot	N/A	A: 10 min. B: 10 min.	12 weeks

BL: baseline; MBM: multiple baseline model; ATM: alternating treatments model; N/A: not available (not reported).

Table 4. The findings in the reviewed studies.

		Reliability		Follow-up		Generalization			Social validity			
Study	Study findings	IOR	TF	Y	N	Y	CM	N	Y	How	N	Limitations
Duquette et al. (2008)	Expressions, gestures, and vocabulary were observed more frequently in P3 and P4 in human applications, eye contact, physical intimacy and facial expressions were imitated more in P1 and P2.	Y/%98	N		+			+			+	Inability to generalize the findings due to the research method
Tapus et al. (2012)	No changes were observed in P2 and P3, eye contact and smiling were observed in P1 and P4 with the robot.	Y/(Kappa) 0.89	N		+			+			+	Robot could imitate only gross motor skills, was slow, orientation was not conducted in baseline but in two application sessions on the same day, the influence of verbal and model cues provided by the practitioner during one-on-one sessions on the independent behaviour of the participant.
Huskens et al. (2013)	Robot and human applications were effective on target skills in all participants, there was no difference between robot and human applications.	Y/0.97 (Kappa) 0.99 (PABAK)	Y/%88–%100 (mean %99)	Y/2 h	+			+			+	Low number of participants, lack of homogeneity in participant age, intelligence and social interaction skills, limited robot behaviour, and lack of social validity data.
Pop et al. (2013)	Low imitation skills and high interactive behaviour with robot in P1 and P2.	–	N		+			+			+	Inability of the robot to speak, low participant group size
Wainer et al. (2014)	Participants had more fun and were interested more in the robot, but exhibited higher interactive behaviour and played interactive games with the human.	Y/0.74 (Kappa)	N		+			+			+	N/A
Desideri et al. (2017)	Participant acquired different levels of target behaviour.	–	N		+			+			+	N/A
David et al. (2018)	Joint attention skill was acquired with extended social cues. There was no difference between robot and human applications.	–	N		+			+			+	N/A
Desideri et al. (2018)	P1 exhibited independent social interaction and target behaviour, while P2 exhibited only independent target behaviour.	–	Y/ Over .8 in-class correlation		+			+			+	It was not determined whether the application effect was due to the robot application or familiarity of the participants; thus the impact of the application was not differentiated, and the demand types and frequency could not be controlled in further sessions
Scasellati et al. (2018)	Joint attention skills improved in adults and caregivers reported that initiation of communication, eye contact and response levels increased, consistent with the findings.	N	N	+	+			+			+	Lack of independent measurement of the robot effect, missing natural intervention opportunities in the sessions due to the focus of the robot on target behaviour, predetermination of target skills and their instruction in short daily activities, and their inadequacy for long-term activities.
Conti et al. (2019)	NAO had a positive impact on the recognition of facial expressions by the child with ASD.	N	N	+/3 m		+	IS				+	The limitation of the data with a single participant.
Fachanditis et al. (2020)	The interaction with the robot was higher when compared to the interaction with the teacher.	E/%86.7–%98.3 (mean: 92.1) IOR	N		+			+			+	Low number of participants, long application duration, inability to determine whether the positive outcome was due to the robot or the novel approach, and the dependence of the methodology on observation and material analysis.
David et al. (2020)	Similar participant performances in waiting on the line behaviour with human and robot applications, while the participants were	Y/ Higher than 0.8 (kappa)	N	+/N/A				+			+	Employment of physical and model cues to ensure that the participants remain seated, lack of long-term follow-up data.

(*continued*)

Table 4. Continued.

Study	Study findings	Reliability		Follow-up		Generalization			Social validity			Limitations
		IOR	TF	Y	N	Y	CM	N	Y	How	N	
	more interested in the robot since they looked at the robot more.											
Desideri et al. (2020)	Preliminary findings demonstrated that Robot RoBò was promising in the improvement of social interaction opportunities and inclusion of children with ASD in uncontrolled settings.	N	N	+/N/A				+			+	N/A

IS: inter-situations; Y: yes; IOR: inter-observer reliability; w: week; m: month; N: no; P: participant (P1 = Participant 1, etc.); CM: collection method; TF: treatment fidelity; N/A: not available (not reported).

expressive language, reacting to own name and verbal requests [55], eye contact, physical intimacy, verbal interaction, and speech [57].

The measurement of the dependent variable

Dependent variables were measured with discrete trial records [16], frequency and duration records [59], event records [18,60,72], frequency records [46,57], time interval records [54,55], rubric scores [52], and four-staged records of intervention phases [73].

Dependent variable criterion

A dependent variable criterion was not determined in any study.

a. *Independent variable:* Six studies were conducted with robots [e.g., 46,60,72,73] and eight with humans and robots [e.g., 18,52,58].
b. *Social robot:* Ten robots were humanoid, one was portable [16], one was a stuffed toy [57], and one was a social robot [73]. Seven humanoid robots were NAO [e.g., 52,55,59], one was ROBO' [56], one was ROBONOVA [46], one was KASPAR [60], and among the other robots, one was DAISY [57] and one was Jibo [73]. Robot visual was utilized in 12 studies [e.g., 16,54,72] and was not utilized in a study [56].
c. *Implementation duration:* Implementation session durations were identified in 11 studies [e.g., 18,59,60], while they were not mentioned in two studies [16,46]. Five studies mentioned total implementation duration [e.g., 56,57,72,73], while eight studies did not [e.g., 46,53–55,59].

Research problem 3: study findings

The study's findings were analyzed based on six variables: (a) research findings, (b) reliability (inter-observer reliability and treatment integrity), (c) follow-up, (d) generalization, (e) social validity, and (f) limitations. Detailed information is presented in the following paragraphs and Table 4.

a. *Research findings:* The impact of social robots on the acquisition of target skills varied. Two studies demonstrated that social robots were effective in the acquisition of target skills in all participants [56,72]. One study reported that both the human implementer and the social robot were equally effective in the instruction of target skills to all participants [18,52]. Another study reported that the social robot was more effective than the human implementer [57]. The studies that reported differences between the effectiveness of the social robot and humans revealed that the social robot led to the acquisition of different skills when compared to the target skill. In one study, two participants established more eye contact with the robot and exhibited smiling behaviour [59], while in another, participants exhibited fewer imitation skills with the robot, while establishing more social interaction [46]. A study reported that the participants had more fun with the robot and exhibited more interest in it, and exhibited higher levels of collaboration with humans during games [60]. One participant developed social interaction and target behaviours without cues, while the other participant only exhibited independent target behaviour [55].
b. *Reliability:* Two types of reliability data were collected in the studies; inter-observer reliability (IOR) and treatment integrity. IOR data were collected in six studies [e.g., 16,58,60], but not in seven studies [46,52,54]. Treatment integrity data were collected in two studies [19,55], but not in 11 studies [e.g., 52,59,72,73].

c. *Follow-up:* Follow-up data were collected in five studies [18,53,54,72,73], and were not collected in eight studies [e.g., 52,57,60], and the longest follow-up period was three months [72].
d. *Generalization:* Generalisation data were not collected in 12 studies, and collected in one study [72]. Generalization was in the form of imitation of the learned facial expressions.
e. *Social validity:* Social validity data were not collected in any study.
f. *Limitations:* Limitations were specified in eight studies [e.g., 16,57,73] and not specified in five studies [e.g., 54,56,60]. Specified limitations included the research design [e.g., 16,57], sample size [18,46,57,72], participant homogeneity [18], robot characteristics [e.g., 18,46,59], inability to determine the impact of the robot due to the intervention [e.g., 55,57,73], inability to measure spontaneous interactions without the robot and to determine whether similar outcomes will develop over a longer period of time [73], different implementer interventions with different cues to make the participants sit at the desk during the sessions [e.g., 53,59], and the lack of social validity [18] and follow-up data [52].

Research problem 4: data analysis

It is critical to understand how data was then analyzed in research to (a) evaluate studies based on data analysis conducted in SCED (i.e., general trends, differentiating aspects), (b) learn which analyses were frequently preferred in robotics research, and (c) understand different analysis options. Thus, "data analysis" was one of the research problems in the current study.

In five studies, only statistical analysis was employed [16,52,57,60,73], two studies were conducted with visual analysis [56,72], and six studies employed both visual and statistical analyses [18,46,53–55,59]. Detailed information on data analysis is discussed in the following paragraphs.

In studies conducted only with statistical analysis, it was determined that dependent sample *t*-test in the SPSS 20 software [57], non-parametric Wilcoxon and Friedman tests [52], Wilcoxon and Mann-Whitney U tests [60], time series analysis with multiple regression [16], dependent samples *t*-test, Pearson correlation and ratio tests [73] were employed. In studies conducted with only visual analysis, behavioural observations were coded based on predetermined scores and plotted on a chart [72,56]. In studies conducted with visual and statistical analyses, David et al. [53] employed inferential statistics, such as Kruskal–Wallis, Mann–Whitney *U* tests, and Tau calculation along with visual analysis to reduce its limitations. By supporting visual analysis with quasi-statistical techniques (Tau-*U* and *p* calculations) [54,55], Tau non-overlap was used for non-overlapping intra-group visual analysis [18], chi-square test and phi coefficient were used for the correlations between dependent and independent variables [46], and visual analysis and IBM SPSS 16 and Mann–Whitney test were used [59].

Research problem 5: the analysis of research based on the basic single-case experimental designs parameters

Basic single-case experimental designs parameters

Before analyzing the studies based on the basic SCED parameters, it was deemed appropriate to discuss the basic features of SCED. Single-case-experimental designs are conducted to reveal the functional relationship between dependent and independent variables [74–77]. In SCED, repeated measurements are conducted on the dependent variable. These measurements are identical, with the exception of the practice of the independent variable, which is carried out according to the implementer's instructions.

The factors that demonstrate the functional relationship between dependent and independent variables in SCED include prediction, verification, and replication. Prediction, verification, and replication reflect the variance in the dependent variable when the independent variable is applied, and all external variables are controlled. Prediction is the estimation of possible changes in the dependent variable when the independent variable is applied. Verification is the verification of the estimate. In other words, it is the verification of the expected change in the dependent variable after the practice of the independent variable. Replication is similar to prediction and verification which reflects the difference between instruction and research. Replication also serves the external validity. External validity is achieved by the replication of the research findings outside the research. The replication required for external validity entails direct and systematic replications. Direct replication includes intra-participant (e.g., ABAB design) or inter-participant replication. Replication is important to test the reliability of previous research findings, the generalizability of the findings, and to identify problems in previous research. In short, it is important to allow other researchers to implement the previous research findings [76–78].

The functional relationship is as important as replication. A functional relationship is the determination of a consistent effect on the dependent variable by systematic manipulation of the independent variable. The presence of a functional relationship in a practice implies that changes in a dependent variable or its level are related to the presence of an independent variable [78,79]. Data on the dependent variable are measured with frequency, duration, event, skill analysis, recorded in data forms, and quantified.

Baseline

The baseline reflects the state of the dependent variable before the independent variable/intervention was applied. The participant's target skill or behavioural levels are measured in this phase.

Intervention

The independent variable is applied systematically in this phase. The main difference between the intervention phase and the baseline is the practice of the independent variable. In this phase, changes in the dependent variable are recorded after the intervention of the independent variable. Examples of the baseline and intervention phases are presented in Figure 2.

The review of the baseline and intervention phases presented in Figure 2 based on the functional relationship would suggest that the increase in the dependent variable during the intervention phase was solely due to the independent variable. The dependent variable data is collected and recorded in data forms. The dependent variable data is collected and plotted, reflecting the performance of the participants in each session as presented in Figure 2. Furthermore, it enables the analysis of the trend, level, and permanence of performance, as well as the execution of numerous computations between successive stages. The dependent variable data are commonly analyzed visually/graphically in SCED [80,81]. Statistical analysis could also be carried out. To establish the correlation between the baseline and the intervention, statistical analyses are performed using parametric and nonparametric tests. Statistical analyses are not common in SCED [77], while visual analysis is still the primary method employed in these studies [82].

The analysis of the studies based on basic single-case experimental designs parameters

The basic SCED parameters include (a) prediction-verification- replication, (b) functional relationship, (c) dependent variable, (d) independent variable, (e) baseline and intervention, (f) internal validity, and (g) external validity.

Prediction-verification-replication

Since it could not be analyzed with visual analysis, the information on prediction, verification, and replication was not presented graphically in the studies. In statistical analysis, it is known that data are validated with t and F tests. Thus, in two studies [57,73], the estimates were confirmed by statistical analysis. In a study conducted with visual analysis [56], the impact of prediction, verification, and replication was observed, while in one [72] it was not. In certain studies where visual and statistical analyses were conducted [18,46,54,56,59], the experimental effect was presented in a graph, in another study [53] prediction and verification were reported.

Functional relationship

The functional relationship between the dependent and independent variables was determined by statistical and visual analysis in the studies. In the analyses, a significant relationship between dependent and independent variables were reported [e.g., 18,46,53,54,56,57]. This demonstrated that there was a functional relationship between the variables.

Dependent variable

Apart from the conceptual equivalent of the dependent variable, it is extremely important to present examples that define or do not define the dependent variable, explain how the dependent variable will be measured, and describe the expected reactions in the dependent variable and the criterion. This determines whether the dependent variable is described with an observable and measurable method and whether it is functional. Thus, it was observed that the dependent variable was not adequately described in certain studies (e.g., it was not written clearly how long the participant should focus on the “focus” dependent variable). In certain studies, the dependent variable was discussed in detail [e.g., 46,53,54,56,59,72,73]. Furthermore, it is unclear how much more the dependent variable should be instructed, as no criteria for the dependent variable were stated in certain trials.

Independent variable

At least one independent variable was the social robot in the studies. It was observed that technical information, such as the size and features of the social robots were included. However, the actions of the social robots (gestures, facial expressions, etc.), whether a verbal or non-verbal interaction was established, and the reactions of the robot to unscripted speech were not mentioned in certain studies [e.g., 54,57,72]. In some, these were discussed in detail [e.g., 16,18].

Baseline (BL) and intervention

BL is the phase before the intervention and participant performance is measured with iterative measurements, and the only difference between the BL and the intervention phase is the implementation of the independent variable [74–76,79]. In studies where statistical analyses were conducted, no measurements were applied in the BL and intervention phases. Except for the studies with graphical analysis ($n = 9$), the percentage or the frequency of the dependent variables were given for BL and intervention sessions. Data on the relationship between variables/phases are determined with mathematical operations and statistical analysis. Variables, such as the details of the sessions in the baseline and intervention phase, the number of trials in each session, the time between the sessions/trials, target stimulus, response interval, and possible responses were discussed in relative detail in certain studies, albeit not all [e.g., 18,53,56].

Internal validity

The studies provided no information on the management of difficulties that could jeopardize internal validity, such as testing, measurement, participant loss, and so on.

External validity

Replication of research and reports that allow for reproducibility serves as a source of high external validity. Thus, participant performances, pre-, and post-behavioural stimuli during the intervention, presentation of these stimuli, response descriptions, and response interval should be reported with a methodology that allows for replication. However, it was observed that certain studies exaggerated external validity despite the lack of relevant evidence [18,52–55].

Discussion

The present study aimed to conduct a comprehensive descriptive analysis on SCED where social skills were instructed to individuals with ASD without any limit on the year of publication. Thus, 13 studies were analyzed based on 18 variables in three categories basic characteristics, methodological characteristics, findings, data analysis, and basic SCED parameters. Each research problem is discussed below.

Research question 1: the studies based on basic characteristics

The six variables analyzed are discussed below:

Country

It was determined that more than half ($n = 8$) of the studies were conducted in Romania and Italy, and the rest were conducted in different countries. In terms of SCED studies may be it was surprising that China and Japan, where several robots are designed and produced, were not among these countries.

Year

Based on the year of publication, it was observed that the number of studies conducted each year has increased recently, especially in 2018 ($n = 3$) and 2020 ($n = 3$). This was consistent with the data reported by Damianidou et al. [63].

Participants

Number of participants. It was observed that the number of participants was at least one and at most 12. The number of participants in SCED also includes issues, such as replication of the participants and how participants with similar traits are investigated. Since the studies were conducted with SCED, the large number of participants in ABAB and other designs, which allow replication with a single participant, would ensure inter-participant replication. Thus, in two studies conducted with only one participant, one study was conducted without inter-participant replication [55] since it was conducted with the ABAB model, and in the study conducted by Conti et al. [72] designed with the ABA′ model, intra- and inter-participant replication were not conducted, reducing the experimental effect. Because two experiments with two participants were designed using the ABAB paradigm, it was hypothesized that inter-participant replication would be impossible. Although it could be suggested that three or more participants could improve replication and strengthen the experimental approach, it was surprising that one study managed to find 12 participants with similar traits [73].

Participant age. It was observed that the participant age varied between pre-school (4 years old) and school age (12 years old). This is consistent with previous study findings [34,40,61]. This could be due to the preference for robotic interventions for individuals with ASD in the developmental period [63]. It was suggested that working with heterogeneous age groups would be beneficial for the observation of the impact of robots on different individuals, and the lack of any studies conducted with robots and older individuals, such as teenagers, young adults, and adults with developmental disabilities was also a limitation of certain studies.

Participant gender. It was observed that 81% of the participants were male and 19% were female. This finding was consistent with previous studies [34,62]. The fact that the number of male participants was four times higher than that of females could be associated with the fact that ASD is 3 times more common among males.

Diagnostic tools. The employment of standard diagnostic tools was reported in 93% of the studies and certain studies also cited the individuals who implemented these tools [e.g., 52,53,59]. Extensive employment of diagnostic tools was consistent with previous study findings [61]. The use of standard diagnostic tools is important for the diagnosis of the individual and the measurement of the individual performance of the dependent variable with various tools. Additionally, past similar studies were claimed to have included a remark, such as "the subject was diagnosed with autism" without identifying the diagnostic method [61]. Thus, it could be suggested that reporting the diagnostic tool could contribute to the literature.

Setting

It was observed that about 78% of the studies were conducted in a therapy room, and 22% were conducted at home and in the classroom. One of the quality indicators in SCED is the clear statement of the settings (e.g., the dimensions, location, characteristics, etc.) to ensure replication [70]. Thus, the setting was underreported in certain studies [e.g., 18,46,52,53], while in others [54,56,73], no information was reported about the settings. However, since it is also associated with the quality of the research, it should be included in more detail. Furthermore, a therapy room is not adequate for the common use of robots in various settings. Further studies are required for teachers who desire to work with larger groups of participants in special education classes and/or families who desire to work at home with their children.

Instructional settings

It was observed that 69% of the sessions were conducted with one-on-one instruction, 8% were conducted in small group settings, and 23% were conducted with dyadic and triadic interaction. The increasing prevalence of ASD may lead to difficulties in providing one-on-one education to these individuals. Thus, small group instruction could be considered. Moreover, it could be advised that small group instruction settings be researched further for effective education and learning through observation possibilities [83]. Triadic interaction could ensure the control of the researcher and allow the individual with ASD to interact with everyone in the setting.

Aim

The studies generally aimed at social interaction and communication skills, such as social interaction behaviour, eye contact, joint attention, taking turns in game sessions, and half of the studies were conducted on the instruction of social skills [e.g., 16,46,54], and the rest were conducted to compare social robot and the human implementer in the instruction of these skills [e.g., 18,59,60]. The research objectives were consistent with previous study findings [34,61,64].

Research question 2: the studies based on methodological characteristics

Research model

It was observed that 92% of the studies were on effectiveness [e.g., 16,59,72,73], while 8% were comparison studies [52]. Almost all studies on effectiveness employed AB models (ABA, ABAB, ABA′, etc.), and one study employed the multiple baseline model. The alternating treatment models were used in all comparison investigations. Research designs were consistent with previous study reports [61]. It is known that prediction, verification, and replication could not be completely conducted in AB models and at least three demonstrations of the experimental effect were not possible. According to Horner et al. [70] and What Work Clearing House [84], one of the indicators of quality SCED is the presence of at least three demonstrations of the experimental effect, which is also a prerequisite of the design standard. It was reported in the literature that this effect could not be demonstrated in various AB models except the ABAB model and was weak experimentally. Thus, it was not possible to conceive why AB models with several limitations were preferred even in recent studies. In studies designed with AB models, the authors should report the limitations due to the employment of these models or they should select the models based on quality indicators in SCED.

Implementers

The fact that the baseline phase was conducted by various implementers, such as therapists, psychologists, and teachers [e.g., 56,72,73] demonstrated that robot interventions could be implemented by different individuals and the robots were easy to manage. In both comparison studies, it was observed that the alternating treatment model was employed to compare human and robot interventions. Since robotics was considered an alternative to human practices, and it was reported that children with ASD interacted with robots better than with humans [64,85], future studies that would compare robot and human practices could expand these findings and contribute to the literature.

Dependent variable

Definition. Certain studies targeted only social skills [e.g., 52,55,60,73], while in others, social skills were instructed with other skills, such as imitation [e.g., 16,46,59]. Findings on the dependent variable were similar to comparable studies [61,62,64]. It could be suggested that the fact that social skills were based on verbal (e.g., greeting expressions) and non-verbal (e.g., joint attention, eye contact) reactions, and they were instructed within various contexts (e.g., during play) served to demonstrate the diversity of social skills. Furthermore, it was considered important to provide various examples for implementers who work with individuals with ASD.

Measurement. In all studies, the measurement of the dependent variable was discussed. It was measured by the frequency of the target behaviour in 85% of the studies and based on the duration of the target behaviour in 15%. The discussion of the measurement of the dependent variable would contribute to a better understanding of the implementation, better interpretation of the findings, and improve the external validity of the research.

Criterion. In all studies, no criteria associated with the dependent variable were reported. Since a criterion was not specified, there was no information about the target percentage or frequency of correct responses to the dependent variable. This could lead to uncertainty for both the researchers and readers. It could be argued that because the experimental process was not detailed, it will be difficult to plan replication studies.

Independent variable

In the studies, 46% of interventions were conducted with robots, and 54% were conducted with humans and robots. Although the effectiveness and efficiency of the two interventions were compared in studies where the robot and human implementers were the independent variables, only two studies were comparative. In effectiveness studies with multiple baseline models [18], there should be only one independent variable; however, the intervention phase was conducted with two independent variables. It could be suggested that this was not consistent with the rationale of effective research. In other studies, conducted with human and robot interventions, it was observed that the independent variable was applied with a change in the phase (e.g., ABB′, ABA′, ABAC). In one study [73] that employed robots, it was determined that the robot was employed in all phases, including the baseline, while in other studies, the robot was employed only in the intervention phase (B, B′).

Social robot

Name. The robots were called NAO, Robonova, Daisy, and Tito based on the country of manufacture. The reasons behind these names were not reported.

Type. Various types of robots were employed in the studies. It was determined that 77% of the studies were conducted with a humanoid robot [e.g., 59,60], 8% were conducted with a non-humanoid stuffed toy [57], 8% were conducted with portable robots [16], and 8% were conducted with social robots [73]. It was observed that NAO was the most popular and employed in almost half of the research. This finding was consistent with previous studies [34,63–65]. The second most popular (14%) robot was DAISY. This finding was in contrast with similar study findings [63]. The preference of certain robots including NAO in research was explained by Aresti-Bartolome and Garcia-Zapirain [86]. They stated that these robots' social interaction competency was adequate, as they allowed the participant to imitate, analyze appearance, facial expressions, and large and small muscle skills. The inclusion of various types of robots was considered to be beneficial in providing different examples for future studies and a choice for implementers.

Visual. It was observed that 92% of the studies included robot visuals and 8% did not. The inclusion of robot images allows the implementers to see beforehand and evaluate them and organize the settings and seating arrangements based on the size of the robot; thus, the presentation of the robot visuals was considered beneficial in studies.

Implementation duration

In 92% of the studies, information on the total duration of the implementation sessions was provided. Sessions lasted between 1 and 27 min. It was observed that the shortest BL session lasted 1 min and the longest session lasted 27 min. The shortest implementation session lasted 10 min and the longest session lasted 25 min. The total implementation duration was reported in 50% of the studies. It was observed that the studies were completed in 1–5 months. Reporting the session and implementation durations would allow the researchers who will conduct similar studies to determine a calendar and plan their schedule. Furthermore, the knowledge of mean implementation durations in various settings, such as school and classroom would allow the teachers/implementers who will work in different settings to estimate how long their study would last.

Research question 3: the study findings

The study findings

The study findings demonstrated that the effect of social robots on participants varied and was uncertain. This was consistent with previous study findings [34,40,61]. In 15% of the studies, it was determined that the social robot was effective on all participants, while its effect was similar to that of the human in 8% and more effective than humans in 8% of the studies. In 72% of the studies, it was reported that the social robot was more effective in various dependent variable dimensions (e.g., in the same dependent variable, participants exhibited lower imitation skills and higher social interaction with a social robot). In general, it was observed that social robots were effective in more than half of the participants. The variations in study findings could be due to the heterogeneity of the spectrum, the inability to select the adequate robot intervention for the individual differences in the participant group [63], and the inability to select the appropriate robotics method [61]. Although the uncertainty of the findings between the participants in the same study or the participants in different studies was an undesired outcome, the social robots were promising, nonetheless.

Reliability

Inter-observer reliability data were collected in 50% of the studies and treatment integrity data were collected in 15%. Inter-observer reliability was calculated with the "agreement/(agreement + disagreement) × 100" in two, and by marking "yes" or "no" in one study. Inter-observer reliability data was consistent with previous study reports [61]. The inter-observer reliability data should be analyzed with the kappa coefficient in robot research [61]. Treatment integrity was calculated with the intra-group correlation coefficient, while one study reported no information. Because only a few studies collected treatment integrity data, there was insufficient information on whether the intervention was carried out as planned. Furthermore, both reliability data are SCED quality indicators. In other words, these two sets of reliability data indicate the quality of the research [70,87]. Thus, it could be suggested that the studies exhibited poor reliability.

Follow-up

It was discovered that follow-up data were collected in 36% of the studies but not in 71%. Follow-up data, similar to the generalization data, were considered inadequate, and this finding was consistent with previous reports [63]. It was observed that the follow-up data were collected after a minimum of two weeks and a maximum of three months. The follow-up data demonstrated the retention of the target behaviour even in the lack of robot intervention. Thus, further follow-up data collection could be recommended in robot studies.

Generalization

Generalization data were collected in 8% of the studies. The fact that generalization data were collected only in a few studies was consistent with previous studies [40,61–63]. It was reported that the most significant concern and problem in social robot literature is the adoption of these robots in the clinical setting [40]. As the collection of generalization data could resolve this issue, the lack of generalization data was inconceivable. However, previous studies with social robots indicated that the instructed skills should be practiced in a natural setting. Furthermore, the lack of generalization data led to a lack of data on the applicability of robot interventions with different implementers in non-clinical settings, and hence a misconception about robot research among implementers and families with children with ASD. Thus, it is necessary to plan the collection of generalization data in future research [61,62].

Social validity

Social validity data were not collected in any study. However, social validity is the view of others on the significance of behavioural changes in a study and the fitness of the selected method to induce the behavioural change [77]. Social validity is more important especially in limited practices, such as robotics research when compared to other technology-assisted interventions (e.g., video models, social stories). Learning the views of the individuals on these interventions would contribute to the planning of future qualified studies.

Limitations

Among the reviewed studies, 69% reported limitations. This could lead to better planning in future studies, smoother experimental processes, and allow the researchers to take precautionary measures. Among the limitations, it could be suggested that participant inhomogeneity was due to the nature of SCED since predetermination of the participants was a prerequisite, and individual differences were not a "limitation" when individuals in the spectrum are considered. The inability to differentiate the impact of the robot effect after the intervention was another reported limitation. This was associated with the impact of the independent variable, and raised questions about experimental control and functional relationship. There are available measures for the problem of the inability to differentiate the effect in SCED and comparison studies (in the case of two interventions). Thus, it could be suggested that these studies did not take the necessary precautions. Furthermore, limitations were associated with the lack of follow-up, generalization, and social validity data as mentioned above.

Research question 4: data analysis

It was observed that two studies were conducted only with visual analysis, and statistical analysis was employed in 11 studies. Visual analyses were conducted with the pre-test–post-test method, not with time series. The data analysis in SCED should be addressed before delving into the analysis of the above-mentioned issue. Statistical and visual analysis are common data analysis methods in SCED. However, despite the availability of only two types of analysis, data analysis has been one of the most debated topics. Although the debate is still on, the majority argues that visual analysis is the more adequate method to analyze the differences between experimental trials and should be preferred in data analysis [76,79,80,88,89]. Despite several advantages, statistical analysis has significant limitations when compared to visual analysis: (a) inability to reflect the changes in individual behaviour in clinical and educational terms [77], in other words, the changes in individual performance (trend, level, etc.) could not be described, (b) since statistical analysis is based on the assumption of independent data and therefore autocorrelation, the data is collected through sequential observations in SCED due to the characteristics of the latter, in other words, it does not fit "partial-dependency" principle, (c) even when there is no improvement in individual performance, statistical analysis may report a significant difference (due to mathematical operations), (d) statistical analysis requires certain knowledge on computers and mathematical operations [74,76,77,80]. Thus, the review of the studies demonstrated that the course of the individual performances (session, calendar, etc.) was not known. Furthermore, experimental phase data, such as the number of sessions, and changes in individual performance were not reported in the studies. Thus, the studies did not provide any examples for the implementers who plan to use robots in educational (e.g., classroom, school) or clinical settings. This suggested once again the differences between research and practice, and led to the question "clinical or statistical significance?" Due to the above-mentioned factors, previous studies stated that statistical analysis should be employed with visual analysis [77,80]. Two more points should be discussed about statistical analysis: First, it was determined that the studies conducted with visual analysis considered the quality indicators employed to determine the design standards in SCED [70,87]. In other words, the studies that were conducted with statistical analysis did not consider these indicators. Thus, studies conducted with statistical analysis could not be analyzed based on the design standards. Second, the effect of an intervention on behaviour/skill was determined, and the effect size was calculated only in studies conducted with visual analysis, and the effect size was not calculated in the studies conducted with statistical analysis.

An in-depth review of the data analysis conducted in the studies demonstrated that in almost half of the studies ($n = 6$), only statistical analysis was employed except for two studies [56,72]. Thus, the trend, level, or variations in participant performance during the sessions conducted in these six studies were not determined. It could be suggested that various implementers would not have the chance to obtain information about the effect of robot interventions on individuals when designing the sessions for their interventions. These six studies include several above-mentioned limitations. This was consistent with previous reports [61]. Furthermore, the review of the robot interventions conducted with extremely sensitive and special participant groups in SCED revealed that the suitability of clinical interventions that focus on behavioural changes for statistical analysis and the information statistical analysis could provide for psychologists, special educators, para-professionals who work with individuals with different disabilities on the sessions, interventions, and the impact of the robots are debatable. In the other half of the studies ($n = 6$), both visual and statistical analyses were employed [e.g., 18,54].

This confirmed the view of several researchers that visual analysis should be complemented with statistical analysis [76,77,79]. In certain studies, authors stated the above-mentioned reasons to justify the tandem employment of visual and statistical analyses [52,53]. The review of the techniques employed in 12 studies (six studies conducted with only statistical analysis, and six studies conducted with both visual and statistical analyses) revealed that more than half ($n = 9$) employed non-parametric techniques, such as Mann–Whitney test, Kruskal Wallis test, and Friedman test. In two studies where parametric techniques were adopted [57,73], dependent sample *t*-test and Pearson correlation and ratio tests were used.

Research question 5: the review of the studies based on basic single-case experimental designs parameters

Certain key parameters in SCED are also the quality indicators. According to Horner et al. [70] and What Work Clearing House [84], or Council for Exceptional Children (CEC), variables that reflect the experimental effect, such as baseline, intervention, and replication are only investigated in SCED. It was reported that prediction, verification, and replication could not be plotted on a graph, and in statistical analysis, the prediction could be verified with t and F tests [77]. In two studies conducted with statistical analysis, only two verified the estimates [57,73]. External validity data should be reported to allow replication for future researchers to conduct similar studies [74,76,77,80]. Replication is also important in applied research, such as SCED (where the independent variable is a clinical intervention). Because in these studies, replication serves both individual differences and generalization [79]. Thus, the experimental processes were poor in terms of replication in the research. For example, most studies did not report the target stimulus, the waiting period, presentation method, the function of the robots, and their responses to participant reactions. To conduct similar studies, the above-mentioned elements should be explained in detail. Based on the independent variable, it was observed that the studies did not report the employment of cues by the social robot, whether it provided reactions independent of its programming, and how it reacted to out-of-context comments and behaviour of the participants. This would both affect replication and misinform future researchers/research groups who plan to employ social robots. A similar trend was observed in the phases. It was observed that the procedures practiced in each phase were not reported in detail. Had the research been conducted with visual analysis, it would have been possible to observe the experimental designs in prediction, verification, and replication. In statistical analysis, it is not possible to obtain information about the levels, trends, or performance of the participants. Thus, the variations in the performance of the participants could not be reported. It was observed that functional correlations were determined by the correlations between the variables using parametric and non-parametric tests. The dependent variable was not clearly defined in certain studies, the dependent variable criterion was not reported in any study, and the reason for the selection of the dependent variable was not identified in almost all studies [e.g., 18,56,59,72]. It was observed that the methods employed to control the factors that could affect internal validity were not reported in any study (e.g., finding further participants to prevent participant loss, aiming to finish the study as quickly as possible due to the maturation factor, the precautions to minimize the testing effect, etc.). Certain studies also differed in SCED reporting. In the method sections, it was observed that information on dependent and independent variables, intervention procedures, response definitions, tools-equipment, data collection, reliability, and settings were incomplete.

It should also be noted here that in previous systematic reviews, none of the previous studies except one [61] reviewed robotics research directly based on SCED. In the study conducted by Begum et al. [61], SCED was discussed based on four factors (baseline, experimental control, presentation of findings, and reliability). However, the three representations of the experimental effect (prediction-verification-replication), internal validity, replication, and functional correlations, which are the basic SCED parameters, were not included. Except for the above-mentioned study, it was quite surprising that robotics research was not analyzed based on research design. This was due to (a) the novel use of robotics research in special education when compared to other technological interventions (video model, alternative supplementary systems), (b) the robots do not directly target individuals with developmental disabilities, (c) robotics research is an interdisciplinary field and the researchers are not used to SCED, and (d) the predominant employment of SCED in fields, such as psychology and education when compared to other research designs (thus, it is perceived as more specific in robot research when compared to other designs). However, the factors that improve the accuracy and reliability of a research method include the knowledge of the method and the practice of the key features of the particular method. Thus, it could be suggested that the present study would guide planning in future SCEDs and contribute to the quality of these. Furthermore, the discussions on the research design and the problems would contribute to the robotics literature.

In conclusion, several social skills were taught in SCED-assisted robotics studies; however, the study findings were inconsistent. Thus, further studies that target social skills instruction with robots should be conducted. It was observed that previous studies were weak based on the employed SCED. Therefore, future studies could be planned and reported based on the standards proposed by Horner et al. [70], What Work Clearing House [84], and Kratochwill et al. [87].

The present study has several advantages and strengths as well as limitations. These included (a) exclusion of various research designs since the present study only reviewed SCED, (b) targeting at least one social skill instruction (e.g., studies that investigated only gaming and imitation skills were not included even if they were conducted with SCED), (c) the inclusion of the studies that reported research design (certain studies that were considered SCED were not included in the analysis since the research design was not specified in the study), and (d) the employment of only a social robot (studies where the social robot was employed as an assistant implementer were excluded).

Based on the limitations and analysis process, the following recommendations could be presented for future research: (a) In addition to SCED, group-experimental designs are also widely used in robotics research. Thus, future studies could be conducted with this research design, (b) similar studies conducted on different skills (gaming, academic, imitation, etc.) could be reviewed, and (c) the present study focussed on individuals with an autism spectrum disorder. Future studies could comprehensively analyze individuals in different disability groups.

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ORCID

Aysun Çolak http://orcid.org/0000-0001-6645-2593

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*References marked with one asterisk indicate studies reviewed for descriptive analyses

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