Robotics for enhancing independent living skills in adolescents and young adults with autism spectrum disorder: a systematic review

Robótica para melhorar as habilidades de vida independente em adolescentes e jovens adultos com transtorno do espectro do autismo: uma revisão sistemática

Robótica para mejorar las habilidades de vida independiente en adolescentes y adultos jóvenes con trastorno del espectro autista: una revisión sistemática

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Abstract
This is a review of studies from the years 2010 to 2021 on the use of robotics to improve the independent living skills of adolescents and young adults with autism spectrum disorder (ASD). Individuals with ASD experience a wide range of challenges, including difficulties in social functioning, one of the core features of the disorder. Rapid progress in technology during recent years, especially in the field of robotics, offers new possibilities of training and education for individuals with ASD. This review addresses specific research questions on the use of robotics in ASD, related to the characteristics of the participants, skills, settings, technologies, data collection methods, evaluation parameters, intervention outcomes, generalization, maintenance, and research rigor. Social skills were the main target in the interventions for adolescents and young adults with ASD. Most of the studies reviewed used questionnaires, and observation as the data collection methods, and the classroom environment and a controlled research environment were the most common settings. Most of the evaluation parameters included the frequency, duration, and number of specific responses. All the studies in the review reported positive results in independent living skills of young people with ASD, but none had conducted generalization and/or maintenance probes. In terms of research rigor, the studies were generally rated as having adequate strength. Robotics appears to be an intervention that shows potential for the enhancement of independent living skills of adolescents and young adults with ASD. Future research should focus on the improvement of work-related social skills of adolescents and young adults with ASD. Exploration of the generalization and the maintenance of the acquired skills should be part of the study protocol.
Keywords: Autism Spectrum Disorder (ASD); Autism; Robotics; Robots; Adolescents; Young adults; Independent living skills.

Resumo
Esta é uma revisão de estudos dos anos de 2010 a 2020 sobre o uso da robótica para melhorar as habilidades de vida independente de adolescentes e adultos jovens com transtorno do espectro autista (TEA). Esses indivíduos experimentam uma ampla gama de desafios, incluindo dificuldades no funcionamento social, uma das principais características do transtorno. O rápido progresso da tecnologia nos últimos anos, especialmente no campo da robótica, oferece novas possibilidades de treinamento e educação para indivíduos com TEA. Esta revisão aborda questões específicas de pesquisa sobre o uso da robótica em TEA, relacionadas às características dos participantes, habilidades, configurações, tecnologias, métodos de coleta de dados, parâmetros de avaliação, resultados de intervenção, generalização, manutenção e rigor da pesquisa. As habilidades sociais foram o principal alvo nas intervenções para adolescentes e adultos jovens com TEA. A maioria dos estudos revisados utilizou questionários e observação como os métodos de coleta de dados, e o ambiente de sala de aula e um ambiente de pesquisa controlado foram os cenários mais comuns. A maioria dos parâmetros de avaliação incluiu a frequência, duração e número de respostas específicas. Os estudos na revisão relataram resultados positivos nas habilidades de vida independente de jovens com TEA, mas nenhum realizou testes de generalização e/ou manutenção. Em termos de rigor de pesquisa, os estudos foram classificados como sendo adequados. A robótica parece ser uma intervenção que mostra potencial para o aprimoramento das habilidades de vida independente de adolescentes e jovens adultos com TEA. Pesquisas futuras devem se concentrar na melhoria das habilidades sociais relacionadas ao trabalho de adolescentes e jovens adultos

com TEA. A exploração da generalização e a manutenção das habilidades adquiridas devem fazer parte do protocolo do estudo.
Palavras-chave: Transtorno do Espectro do Autismo (TEA); Autismo; Robótica; Robôs; Adolescentes; Jovens adultos; Habilidades de vida independente.

Resumen
Esta es una revisión de estudios de 2010 a 2020 sobre el uso de la robótica para mejorar las habilidades de vida independiente de adolescentes y adultos jóvenes con trastorno del espectro autista (TEA). Estas personas experimentan una amplia gama de desafíos, incluidas las dificultades en el funcionamiento social, una de las principales características del trastorno. El rápido avance de la tecnología en los últimos años, especialmente en el campo de la robótica, ofrece nuevas posibilidades de formación y educación para las personas con TEA. Esta revisión aborda preguntas de investigación específicas sobre el uso de la robótica en los TEA, relacionadas con las características, habilidades, entornos, tecnologías, métodos de recopilación de datos, parámetros de evaluación, resultados de la intervención, generalizabilidad, mantenimiento y rigor de la investigación de los participantes. Las habilidades sociales fueron el principal objetivo de las intervenciones para adolescentes y adultos jóvenes con TEA. La mayoría de los estudios revisados utilizaron cuestionarios y observación como métodos de recopilación de datos, y el entorno del aula y un entorno de investigación controlado fueron los escenarios más comunes. La mayoría de los parámetros de evaluación incluyeron frecuencia, duración y número de respuestas específicas. Los estudios de la revisión informaron resultados positivos en las habilidades para la vida independiente de los jóvenes con TEA, pero ninguno realizó pruebas de generalización y/o mantenimiento. En términos de rigor de la investigación, los estudios se calificaron como adecuados. La robótica parece ser una intervención que muestra potencial para mejorar las habilidades para la vida independiente de los adolescentes y adultos jóvenes con TEA. Las investigaciones futuras deberían centrarse en mejorar las habilidades sociales relacionadas con el trabajo de los adolescentes y adultos jóvenes con TEA. La exploración de la generalización y el mantenimiento de las habilidades adquiridas debe ser parte del protocolo de estudio.
Palabras clave: Trastorno del Espectro Autista (TEA); Autismo; Robótica; Robots; Adolescentes; Adultos jovenes; Habilidades para la vida independiente.

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder due to which affected children may face difficulties in various aspects of social functioning, including making and maintaining eye contact, establishing emotional and social reciprocity, and the ability to comprehend facial expressions and body language. In addition, stereotypical gestures and repetitive or restricted sets of behaviors, and even aggressive behavior, are not uncommon among individuals with ASD (American Psychiatric Association, 2013). The American Autism and Developmental Disabilities Monitoring Network estimated the rate of ASD in the United States to be 1 in 54 (Maenner et al., 2020), whereas in 2016 the estimate was 1 in 68 (Baio et al., 2016). The increasing rate of ASD diagnosis has led many researchers to focus on the transition to adulthood, since some of the most challenging characteristics of ASD may become more obvious and more distressing in adolescence, as social demands become more complex with age (Webb et al., 2004). Adolescents and young adults with ASD, who fail to interact effectively with their peers, may often be rejected.

Independent living skills are important for the community participation of young people, and they encompass a wide variety of abilities including social, vocational, academic, daily living, and behavior management skills (Benett and Dukes, 2014). Adolescents and young adults with ASD often leave school without the necessary living skills which leads them to poor outcomes in community integration, social interaction, post-secondary education, and employment (Wehman et al., 2014). Most of them continue to live at home with their parents even when they are older. Howlin and colleagues (2004) found that fewer than 10% of individuals with ASD live independently. Unemployment and underemployment of adolescents and young adults with ASD is one of the major problems they face after leaving school. Their lack of social skills (i.e., social competence, nonverbal communication, eye contact, understanding of facial gestures and body language) is directly connected to poor performance during job interviews (Strickland et al., 2013).

Recent technology-based methods have been implemented in interventions with individuals with ASD, aimed at improving a wide range of skills (Bennett & Dukes, 2014). The use of robots shows promise, since it provides scope for helping individuals with ASD to develop social skills (Zheng et al., 2016). Researchers, teachers and health practitioners have used robotics in interventions with individuals with ASD, who appear to demonstrate a higher degree of task engagement when interacting with robots than with human adults (Warren et al., 2015). A variety of robots (e.g., humanoid, android, industrial, telerobots, autonomous) have been used as intervention tools for individuals with ASD, incorporating programmed behavior for replacing the human instructor, to enable them to complete a specific task.

Since 2016, several reviews concerning ASD and robotics have made contributions to the exploration of various aspects of this topic. Toh and colleagues (2016) examined the use of robots in early childhood and in the lower levels of education. Their review showed that robots can influence the development of cognitive, conceptual, language, social and collaborative skills of young children with ASD, but the findings related to the parental perception of the use of robots in their children's education were mixed. In 2016, Pennisi and colleagues in their comprehensive review of social robots in ASD treatment reported that studies show that ASD subjects often perform better with a robot partner than a human partner, and show a variety of social behaviors towards robots, and during treatment sessions their repetitive and stereotyped behaviors were reduced, and their spontaneous language improved. The most recent review was published in 2020 by Raptopoulou and colleagues, whose findings suggested benefits in using human-robot interaction to assist with the development of social skills for children with ASD.

Given their impairments and the difficulties that individuals with ASD face and their requirements for training in independent living skills, there is a need to better understand the findings of robotics research related to the enhancement of independent living skills for adolescents and young adults with ASD. The current review examined studies that included adolescents and young adults with ASD, and it focused on the development of independent living skills in this population. The review was based on the following research questions:

- What were the characteristics of the participants in the studies?
- What independent living skills for adolescents and young adults with ASD were taught through the robotic interventions?
- Which technologies were used in the studies?
- Which data collection methods were used in the studies?
- In what settings were the studies conducted?
- Which evaluation parameters were used to analyze the performance of the participants in the studies?
- What were the intervention outcomes for adolescents and young adults with ASD after the implementation of robotic interventions?
- Were generalization and maintenance of the acquired learning skills supported by the robotic interventions?

2. Method

This review focused on interventions for adolescents and young adults with ASD. Each of the studies included in the review that met the predetermined criteria was analyzed and summarized in terms of skills, participants, technologies, data collection methods, settings, evaluation parameters, intervention outcomes, generalization, maintenance, and research rigor.

2.1 Search procedure

Five electronic databases were selected to search for primary studies for this review, Education Resources Information Centre (ERIC), Scopus, Science Direct, PubMed, and Scholar Google. The studies selected for review were written in English, appeared in peer-reviewed journals, and were limited by publication date. The keywords used were: ASD, robotics, adolescents, young adults, independent living skills. Combining ASD OR autism AND robotics OR robots AND independent living skills OR skills AND adolescents OR young adults. The initial search resulted in 365 prospective studies, which, after removal of duplications were reduced to 352. The remaining studies were analyzed based on the selection criteria of the review. First, the title of the study was considered, and then the abstract was read, to exclude studies that did not include experimental results of intervention programs, and those which presented different age groups, and/or disabilities not including ASD. The remaining studies were screened by the authors for adherence to the inclusion and exclusion criteria as discussed below. Checking of the references of the remaining studies revealed no further prospective study. A hand search of the peer-reviewed articles was conducted, and finally, the then studies were identified for inclusion in the review (Figure 1). Interrater agreement (IRA) during the database search, ancestral and hand search, and screening was based on separate examination by the researchers. Overall agreement was 90% and a consensus was reached to resolve the few disagreements.

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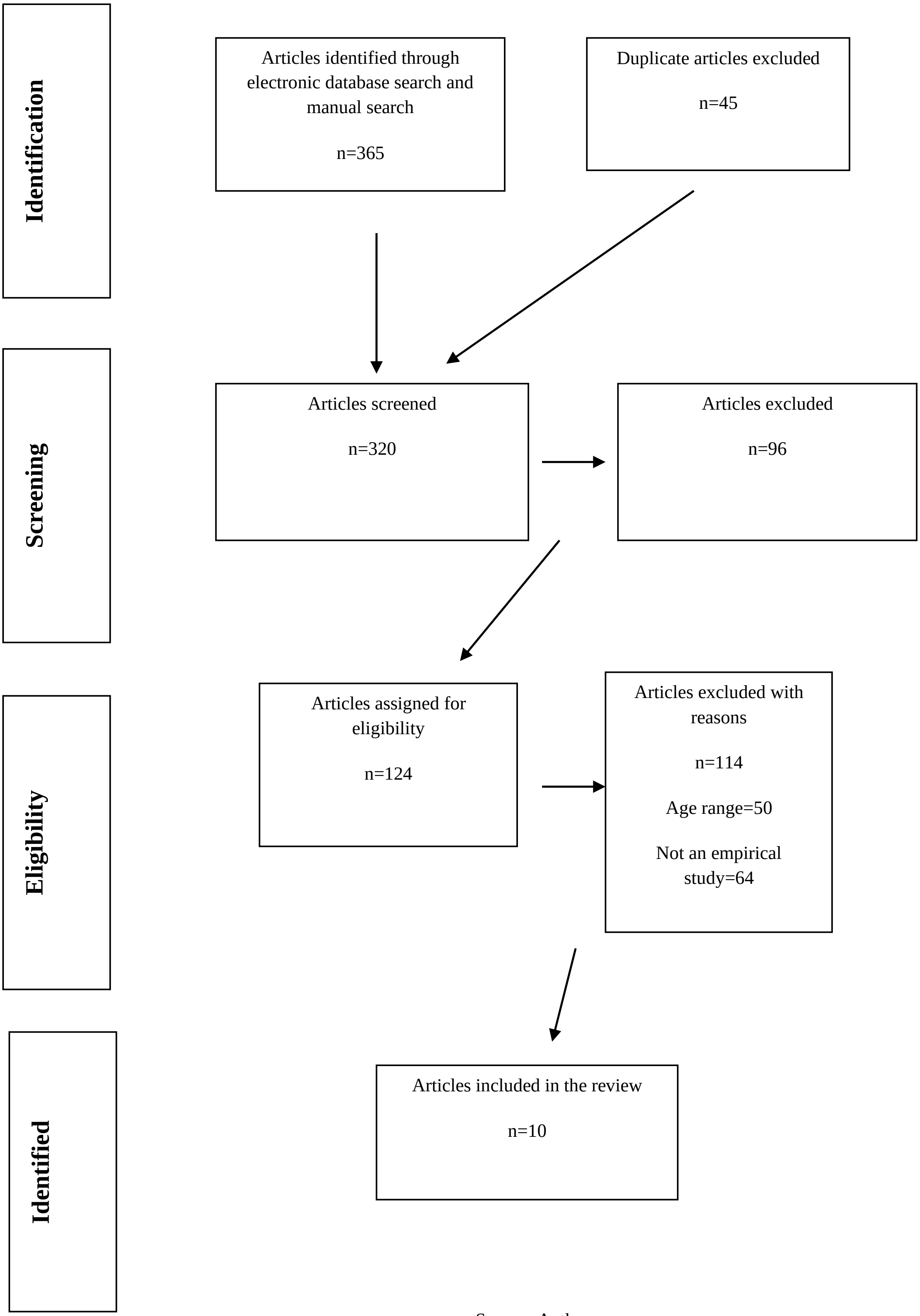
Figure 1. Prisma flowchart of the process and the results of the search strategy for articles on robotic intervention for adolescents and young adults with autism spectrum disorder.



Source: Authors.

2.2 Inclusion and exclusion criteria

The following inclusion criteria were applied to determine the studies that would be included in the review: a) the studies focused on robotic intervention for adolescents and young adults with ASD; b) the participants were aged between 12 and 24 years and had been diagnosed with ASD; c) the studies were published between 2010 and 2021 (the year 2010 was chosen because in a rapidly evolving technological field such as robotics, studies older than ten years might refer to technology considered partially obsolete); d) the studies were written in English.

Studies were excluded from the review if they: a) were non-experimental; b) did not include at least one participant aged 12 to 24 years. Studies were included that targeted adolescents and young adults aged less than 24 years or in which the mean age of the participants was <24 years at the start of the intervention. Grey literature (e.g., dissertations, chapters, etc) were excluded.

The two researchers completed the search and the evaluation independently and determined whether a study met the inclusion criteria. The selected studies were then compared for reliability, which was calculated using percent agreement on the articles that each author identified as meeting the inclusion criteria. Any possible disagreement between the two researchers was discussed until they agreed. Finally, the IRA was 90%.

2.3 Coding procedure

Each study was coded to assess its quality based on the Evaluative Method for Determining Evidence-Based Practices in Autism, which has been reported to have good to excellent reliability and validity (Reichow et al., 2008). The following coding categories were used for the study data: a) participant' characteristics (number, age, diagnosis), b) skills targeted in the study, c) technical data (technologies used, the names of the robots, number of sessions), d) evaluation data collection method (questionnaire, interviews, observations, etc), e) setting (classroom, home, controlled research environment, etc.), f) evaluation parameters, g) outcome, h) generalization, i) maintenance, j) research rigor.

To evaluate the rigor of the studies, one rubric was developed for group studies and one for single-subject studies, which included primary quality indicators and secondary quality indicators. Each study was rated as strong, acceptable/adequate, or weak. Common primary quality indicators for group and single-subject studies included participant characteristics, independent variables, and dependent variables, and common secondary quality indicators included interobserver agreement, blind raters, fidelity, generalization and/or maintenance, and social validity.

The two researchers reviewed the ten studies to determine whether each met the coding categories and the Evaluative Method for Determining Evidence-Based Practices in Autism. The data extracted in this process are shown in Tables 1 and 2. The IRA for the coding procedure calculated by dividing the sum of the agreements by the total sum of the agreements and disagreements multiplied by 100 was 90%.

Table 1. Review of robotic interventions for adolescents and young adults with autism spectrum disorder (ASD) 2010-2021: Characteristics of the participants, skills targeted, research data, data collection methods, setting.

Study	Participants (age, number, diagnosis)	Skills targeted	Number of sessions, technology used, name of the robot	Data collection methods	Setting
Jordan et al. (2013)	3 (ASD group) 3 (other cognitive impairments group) Age=19-21 years	Paying attention, communication, and social skills	15min per session Robotics, a smartboard, conventional playing cards Yujin Robot Co. Ltd, Seoul, Korea	Observation, video recordings	School
Kaboski et al. (2014)	8(M=8, ASD group, M.A.=14.05) 8 (M=8, TD group, M.A.=13.83)	Reduction social anxiety Improvement in social/vocational skills	3h/day for 5 consecutive days Robotics Nao	Parent report, observation	Pilot summer camp
Kumazaki, Warren, Corbett et al. (2017)	7 (M=6, F=1, M.A.=23.1; Android-robot mediated group) 8 (M=6, F=2, M.A.= 23.4; Independent study group)	Bolstering self-confidence and reduction of biological levels of stress	10 min per session from day 1 to day 5 at the same time of day Android robot, Actroid-F	Questionnaire, real-time observation	NM
Kumazaki, Warren, Muramatsu et al. (2017)	16 (M=15, F=1, M.A.=12.6)	Preferences regarding the appearance of the robot	Sequence of 3 interaction conditions in random order (average duration 5 min). Android robot, mascot robot, mechanical robot	Questionnaire, semi-structured interview	Standard clinical assessment room
Kumazaki et al (2019)	13 (M=9, F=4; M.A.= 21.9, IGT AND JUA group) 13(M=12,F=1, M.A.=21.9; IGT group)	Job interview skills	30 min per session from day 1 to day 7 at the same time of day Android robot, Actroid-F	Questionnaire, real-time observation	NM
Kumazaki et al. (2021)	20 (M=8, F=2, RMC group; M=9, F=1, TCT group) M.A.=19.8 (RMC group) M.A.=20.1 (TCT group)	Maintenance motivation for training (ASD) Improvement of communication skills	Once a week over 4 weeks (for a total of 5 sessions; 50min per week for TCT group; 15min per session for RMC group) PC, teleoperated robot; CommU	Observation (video camera), questionnaires (Self-rated, rated by their teacher)	Class
Kumazaki et al. (2018)	11(M=9, F=2, M.A.= 15.91; ASD group) 8 (M=4, F=4, M.A.= 15.73; TD group)	Communication skills	Sequence of 3 interaction conditions in random order; average duration 5 min. Android robot, Actroid-F and visually simple robot, CommU	Questionnaire, real-time observation, audio recordings	Standard clinical assessment room
Silva et al. (2020)	15 adults (M=12, F=3), M.A.=36 years 10 children (M=10), M.A.=7	Improvement in imitation skills	3 test sessions-1 test session per experimental condition, separated by a 1-week washout period Zoomer dog from SpinMasterTM (Toronto)	Observation, Video-recording	Quiet room either at home (adolescents) or the day center in which they were enrolled (adults)

Yoshikawa et al. (2019)	4 (M=4, Age= 15-18 years; ASD group) 6 (M=6, Age= 15-18 years; Non ASD group)	Face-to-face communication and creation of easier experiences transferable to humans	5 consecutive sessions in total alternately in each room on the same day Android robot, Actroid-F	semi-structured interview	Human and android room
Yuen et al. (2014)	2 (M=2, Age=12-14 years, ASD group) 8 (M=4, F=4, Age=12-14 years; Non ASD group)	Levels of social interactions	A five-day camp spread over 5 Saturdays at the start of the spring semester. Each camp day was split into one-and-a-half-hour sessions. The robotic situation lasted for 11 sessions, and the nonrobotic situation 9 sessions. LEGO NXT Mindstorms robotic kits, Nonrobotics instruction focused on other STEM topics, such as astronomy, computer programming, and earth science.	Social skills assessment, video recording (only peer-to-peer social interactions were recorded), observation (during unstructured activities), a 10-item fidelity of implementation checklist was used daily to ensure that all instructional sessions and data collection adhered to the same format and length of time	STEM education center at a University

Note. ASD=Autism Spectrum Disorder, F= Female, h=Hour, JUA=Job interview training program using an android robot, IGT=Interview guidance by teachers, M=Male, M.A.= Mean Age, min=minutes, NM=Not mentioned, PC=Personal Computer, RMC=Robot-mediated communication exercise, STEM=Science Technology Engineering Mathematics, TCT=Taking a class by teachers alone, TD=Typical Development,
Source: Authors.

3. Results

As described above, ten studies met the inclusion criteria and were submitted to the coding procedure. The summary of the studies in terms of skills targeted, participants, technology, data collection methods, and setting used are presented in Table 1, while other details, including evaluation parameters and outcomes of the studies, generalization, and maintenance are presented in Table 2.

3.1 Participant characteristics

The 10 studies included a total of 163 participants with a sample size ranging from six to 26 participants. Most of the participants were male (132/163; 81%), 25 were female, and the gender of the remaining six was not reported. All the studies included participants with ASD, and one study also included participants with stroke, cerebral palsy, and Duchenne muscular dystrophy. Four of the ten studies included an ASD group and a typical development (TD) group.

3.2 Targeted skills

Several skills were targeted in the studies including attention, self-confidence, social interaction, face-to-face communication, social skills, vocational and job interview skills, techniques for reducing social anxiety and stress, and imitation skills. Social communication skills were targeted in six studies, vocational skills in two studies, and the remaining skills in one study each. In 4/10 studies two or more skills were targeted. The studies are grouped below, based on the skills targeted in alphabetic order.

Appearance preference: Kumazaki, Warren, Muramatsu, and colleagues (2017) evaluated the preferences of the participants regarding the appearance of the robots in a group of adolescents with ASD. specifically, they investigated the preferences of high-functioning adolescents with ASD using three types of robots with different appearances: an android robot resembling an adult woman, a mascot robot with humanoid form and a cartoonish appearance, and a mechanical robot with a humanoid form, but with many visible mechanical parts. The robots were all teleoperated to perform semi-structured conversations with the study subjects. Significant preference was observed for the humanoid robot over the more mechanical or mascot-like robots.

Attention: Jordan and colleagues (2013) conducted a study to investigate the use of robotic technology during a specific activity, namely playing a card game for promoting attention, communication, and social skills in adolescents with ASD. The participants were observed during a card game using a humanoid robot, a SmartBoard, or conventional playing cards. The observed behavior was grouped into two categories, "interaction" (e.g., one participant watching the other) and "intra-action" (e.g., one participant not playing, not paying attention to the game or to another participant), and measured by duration.

Communication skills: Yoshikawa and colleagues (2019) evaluated whether android robots can take the role of training partners in face-to-face communication for individuals with ASD and create techniques transferable to humans. Adolescents participated in a pilot experiment in which they participated in alternate sessions of semi-structured conversation with either a human female or a female type android robot, five times in total. The preliminary results indicated positive signs of robotic success, since the participants, regardless of whether they were of TD or ASD tended to look more at the face of the android robot than that of the human.

Kumazaki and colleagues (2018) compared the reported preference of adolescents with ASD and peers of TD in communicating with two different robotic systems, android and simplistic humanoid, and with a human interviewer. Each participant completed a sequence of three interactions in random order and semi-structured interviews, and the interaction was timed.

Kumazaki and colleagues (2021) also developed a communication training system using a teleoperated robot. The participants were grouped in pairs and randomly assigned to either taking a class with teachers alone (TCT) or a robot-mediated communication exercise (RMC) group, and communicated with each other through the robot. The objective was to test whether this system can maintain motivation for training in individuals with ASD and whether to evaluate its usefulness for enhancing communication skills. The participants self-rated describing their thoughts to others, and being good at listening to the thoughts or feelings of others was rated both by themselves and by their teachers.

Imitation skills: Silva and colleagues (2020) provided a preliminary evaluation of contact with dogs as an approach to eliciting spontaneous imitation in people with ASD. They tested the effect on performance of contact with a friendly dog before a spontaneous imitation task. The participants completed the spontaneous imitation task under three experimental conditions: after a free-play interaction with the live dog, after a free-play interaction with a robotic dog, and after a waiting period that involved no stimuli. The imitation ratio, imitation accuracy, and indicators of social motivation were assessed during the task.

Job interview skills: Kumazaki and colleagues (2019) developed a job interview training program using an android robot, consisting of three stages. The participants were randomly assigned to two groups, one of which received a combined intervention with “interview guidance by teachers and job interview training program using an android robot”, and the other received intervention with interview guidance by teachers alone. The participants in the first group showed improved nonverbal communication skills and self-confidence, whereas and a reduction in stress and social anxiety symptoms. For evaluation the physiological responses, the participants provided salivary samples for cortisol analysis on days 1 and 7.

Self-confidence: Kumazaki, Warren, Corbett, and colleagues (2017) evaluated the feasibility and efficacy of android-mediated mock job interview training in comparison to a psycho-educational approach human interview, in terms of bolstering self-confidence and reducing biological levels of stress. The participants were randomized to participate either in a mock job interview training with the robot system or a self-paced review of materials about job-interviewing skills.

Social interaction: Yuen and colleagues (2014) observed the levels of social interaction of two middle school children, A and B, with high-functioning ASD during collaborative robotics projects. The duration of social interactions for child A was better during the robotic sessions than during other science, technology, engineering, mathematics (STEM) lessons. Child A also showed higher levels of peer interaction during structured activities. Child B, on the other hand, showed longer periods of social interaction with peers during unstructured activities.

Vocational skills: Kaboski and colleagues (2014) evaluated a novel intervention for facilitating social interaction between adolescents with ASD and their peers of TD, designed to reduce their social anxiety and improve their social/vocational skills. The participants had to program the robot to be social (e.g., to interact, tell a joke) with the crowd, and to demonstrate each of the programming skills. When programming the robot to carry out behaviors or conversation, they become more aware of the function and effectiveness behind the gestures and words used in natural interactions (e.g., language, eye contact, gestures, when to pause, when to follow up with a question, etc.). All the participants completed the intervention, including baseline and post-test sessions.

3.3 Technologies

In the studies reviewed various different types of robots were part of the intervention. In two studies combination technology elements were used: android robot; ACTROID-F, mascot robot; Smile Supplement Robot, mechanical robot; M_3-Synchy (Kumazaki, Warren, Muramatsu et al., 2017); android robot; ACTROID-F, visually simple robot; CommU (Kumazaki et al., 2018). In the study of Kumazaki, Warren, Muramatsu, and colleagues (2017) the robots had a humanoid form, but the degrees of human likeness were varied. The ACTROID-F is a female-type humanoid robot with an appearance similar to that of a real person (i.e., facial features, hair color, hairstyle, height), whereas the mechanical robot M_3-Synchy is a child-sized humanoid robot with many visible mechanical parts. The Smile Supplement Robot has a humanoid form with a cartoonish appearance (i.e., it is dressed in a pumpkin outfit). Kumazaki and colleagues (2018) used the android robot ACTROID-F and a visually simple robot CommU, which has a limited number of body parts (i.e., head, torso, waist, two arms) and is less humanlike than the ACTROID-F.

In the study of Silva and colleagues (2020), the participants completed an imitation task after a free-play session with a live dog, then after free-play interaction with the robotic Zoomer dog, and finally after a waiting period that involved no stimuli. The Zoomer dog can be programmed to act autonomously, imitating the behavior of a live dog (e.g., rolling, sitting, barking, and approaching a people). Kumazaki, Warren, Corbett, and colleagues (2017) involved the participants in mock job interview training with ACTROID-F, or with a self-paced review of materials about job-interviewing skills (i.e., read and answer materials about questions often asked in a real job interview). In the study of Jordan and colleagues (2013), two technological modes (i.e, the Yujin robot and the SmartBoard) and a traditional card game were used. The Yujin robot has movable arms and a touch screen display. It has eyes, mouth, cheeks that can produce facial expressions, and has wheels on which to rotate.

The remaining five studies used only one robot: the android robot ACTROID-F (Kumazaki et al., 2019; Yoshikawa et al., 2019); Nao (Kaboski et al., 2013); LEGO NXT Mindstorms robotics kits (Yuen et al., 2014); Comm-U (Kumazaki et al., 2021). Nao is a humanoid robot with text-to-text communication and freedom of movement that allows for human-like social gestures. LEGO NXT Mindstorms is a programmable robotics kit, which contains various elements (i.e., ultrasonic sensors, contact sensors, bricks, and pieces) for building any kind of robot.

3.4 Data collection methods

The three main data collection methods were used in the various studies, namely questionnaires, observation and interview. The main methods were observation (either video recording or real-time) and questionnaires. Only three studies applied one method: observation (Jordan et al., 2013, Silva et al., 2020); semi-structured interview (Yoshikawa et al., 2019), while the others combined two methods: report and observation (Kaboski et al., 2014); questionnaire and observation (Kumazaki, Warren, Corbett, et al., 2017, Kumazaki et al., 2018, Kumazaki et al., 2019, Kumazaki et al., 2021); questionnaire and semi-structured interview (Kumazaki, Warren, Muramatsu, et al., 2017); observation and social skills assessment (Yuen et al., 2014).

3.5 Settings

Three types of settings were used the studies, mainly the school environment, either a classroom (Jordan et al., 2013, Kumazaki et al., 2019), or a STEM education center at a University (Yuen et al., 2014), a pilot summer camp (Kaboski et al., 2014), and a controlled research environment, specifically a standard clinical assessment room (Kumazaki, Warren, Muramatsu, et al., 2017, Kumazaki et al., 2021, Yoshikawa et al., 2019). In two studies the setting is not defined (Kumazaki, Warren, Corbett, et al., 2017; Kumazaki et al., 2019), while in one study there was the option to use a quiet room, either at home (adolescents) or the day center in which the young adults were enrolled (Silva et al., 2020).

3.6 Evaluation parameters

The most commonly used evaluation parameters included observation of frequency of “useful” and “non-useful” behaviors (Jordan et al., 2013), or of responses: physiological responses (Kumazaki, Warren, Corbett, et al., 2017; Kumazaki et al., 2019); responses to name (Silva et al.,2020), and preferences (Kumazaki, Warren, Muramatsu, et al., 2017), but also the ratio of number of words used (Kumazaki et al., 2018), communication performance and interaction effects (Kumazaki et al., 2021), and the duration of social contact: eye gazing and physical contact (Silva et al., 2020); social interaction (Yuen et al., 2014), and the looking-face ratio (Yoshikawa et al., 2019), and the culmination of all of the knowledge and skills (Kaboski et al., 2014).

3.7 Outcomes

The outcomes of the intervention programs for adolescents and young adults are presented in Table 2. All the studies in the review reported positive results. Most of the participants in the robotic intervention programs showed less repetitive behavior when they played games with the robot or the smart board than with playing cards (Jordan et al., 2013). During robotic intervention, they showed a reduction in self-reported social anxiety (Kaboski et al., 2014; Kumazaki, Warren, Corbett, et al., 2017), an increase in their knowledge of robotics (Kaboski et al., 2014) and enhanced confidence (Kumazaki, Warren, Corbett, et al., 2017). In the study of Kumazaki, Warren, Muramatsu, and colleagues (2017) differences in preference were noted, with participants with higher levels of reported ASD symptomatology preferring the android robot. Higher levels of enjoyment were reported for adolescents with ASD in conversing with the android robot, although they did not show higher rates of self-disclosure (Kumazaki et al., 2018). In the combined interview guidance by teachers (IGT) and job interview training program using an android robot (JUA) project, significant improvement for participants with ASD was reported in posture, voice volume, nodding, and facial expression (Kumazaki et al., 2019).

Other studies reported improvement in various communication skills, specifically listening to the thoughts or feelings of others (Kumazaki et al., 2021; Yuen et al., 2014), and in eye gaze; participants with ASD looked less at the human eye region than non-ASD participants, and looked at the android eye region more than at the human eye region (Yoshikawa et al., 2019). Silva and colleagues (2020) reported that the adolescents with ASD appeared more motivated and engaged more frequently in spontaneous imitation in the live dog situation than in the other situations (i.e., free-play interaction with a robotic dog, or after a waiting period that involved no stimuli). In addition, they appeared to need fewer prompts before responding to their name in the dog situation than in the other situations.

Table 2. Review of the robotic interventions for adolescents and young adults with ASD: Evaluation parameters and Outcomes.

Study	Evaluation parameters	Outcomes	Generalization	Maintenance
Jordan et al. (2013)	Interactions (e.g., "useful" behaviors such as one participant watching the other play the game) and intra-actions (e.g., "non-useful" behaviors such as a participant who was not paying attention to the game or other participant; lack of interest)	Highly individualized patterns of behavior Repetitive behavior was less in participants with ASD when using both the robot and the SmartBoard than when using playing cards.	NC	NC
Kaboski et al. (2014)	Ability to program the robot to be social with the crowd Demonstrate each of the learned programming skills	Reduced self-reported social anxiety in highly verbal adolescents with ASD Increased knowledge of robotics in both groups	NC	NC
Kumazaki, Warren, Corbett et al. (2017)	Evaluation of physiological responses; participants also provided samples for salivary cortisol measurement after the human interviewer sessions, at the same time each day (i.e., after the experimental session or at a scheduled time for the control condition)	Significant rise of salivary cortisol between Day 1 and Day 2 in the android robot-mediated group, suggesting enhanced physiological arousal in the new setting of the mock job interview by the android robot Simple exposure to the android robot-mediated interview procedures contributed to the trend of self-reported increases in confidence and corresponding reductions in biological indicators of stress/anxiety.	NC	NC
Kumazaki, Warren, Muramatsu et al. (2017)	Preferences regarding the appearance of the robot	Only 4/16 high-functioning individuals with ASD preferred to interact with the M3 -Synchy (mechanical robot) over the other two options. Half of the participants identified the mascot robot as their favorite. There appear to be significant differences in preference; individuals with higher levels of reported ASD symptomatology prefer the ACTROID-F (android robot) to the M3 -Synchy (mechanical robot) or the Smile Supplement Robot (mascot robot).	NC	NC
Kumazaki et al. (2018)	Reported preference in communicating with two types of humanoid robots and human interviewer, and the ratio of change in the measured length of disclosure statements, to examine differences between adolescents with ASD and control subjects of TD.	ASD adolescents reported higher levels of enjoyment while conversing with the visually simple robot and demonstrated a greater level of self-disclosure with the visually simple robot, than with TD peers. Adolescents with ASD reported high levels of enjoyment in conversing with the android robot, but did not show higher rates of self-disclosure with the android. Interactions with both robots were a positive experience for adolescents with ASD.	NC	NC
Kumazaki et al (2019)	Performance in nonverbal communication (i.e., posture, gaze, voice volume, nodding, and facial expressions). To evaluate the physiological responses, the participants provided salivary samples for cortisol measurement on days 1 and 7.	Significant improvement in posture, gaze, voice volume, nodding, and facial expression in the combined IGT and JUA group than in the IGT only group. The self-confidence of the combined IGT and JUA group improved significantly more than the IGT-only group. The improvement exhibited by the combined IGT and JUA group in the S4 (40 min after the mock job interview) was more than that of the IGT-only group.	NC	NC
Kumazaki et al. (2021)	Describing thoughts to others, listening to the thoughts or feelings of others	Motivation for training using this system was maintained during the session Improved communication skills (e.g., listening to the thoughts or feelings of others)	NC	NC
Silva et al.	The spontaneous imitation task involved four manual	Adults showed no differences in imitation between situations; adolescents	NC	NC

(2020)	actions (clap hands, pat legs, touch nose, wave goodbye) and two orofacial actions (protrude tongue, make a noisy kiss). As indicators of social motivation, the researchers assessed response to name (i.e., mean number of calls it took a participant to look up) and the participant' s emotional expressions during testing. As a measure of engagement with the stimuli, the total duration of the participant's social contact (i.e., eye gazing and physical contact) with the dog and the robot was coded.	engaged more frequently in spontaneous imitation in the live dog situation than in the other two situations. Adolescents showed more positive emotional expressions and needed fewer prompts before responding to their name in the live dog situation than in the other situations		
Yoshikawa et al. (2019)	Analysis of when the detected fixation points remained on the human's or android's face in the captured images (looking-face and looking-eye ratio), and when they looked at the human interlocutor's face.	Participants in both groups looked at the android more than at human interlocutors. ASD participants looked less at the human eye region than non-ASD participants and looked at the android eye region more than at the human eye region. The time looking at the eye of the human interlocutor increased with an increasing number of sessions in the ASD group (marginally significant).	NC	NC
Yuen et al. (2014)	Assessment of levels of social interaction across two categorical variables: the content of instruction (robotics versus non-robotic), and the type of environment (structured versus non-structured). The duration of social interaction in the instruction types was measured. Proximity alone was insufficient to meet the criteria for social interaction. No qualitative measures were employed to differentiate desirable social behavior from inappropriate social behavior.	The duration of social interaction for Student A more closely resembled that of non-ASD peers during the robotics condition than during other STEM area lessons. Student A also showed higher levels of peer interaction during structured activities, such as the instructional activities organized throughout the day. During unstructured activities (e.g., transitions, breaks, and lunch), Student A interacted primarily with adults (including researchers, parents, and instructors) rather than peers. Student B displayed longer intervals of social interaction with peers during unstructured activities, but far lower rates during structured activities than peers, including Student A. For both students, more social interactions were initiated at the beginning and the end of the camp, and less in the middle, during robotics instruction.	NC	NC

Note. NC=Not Conducted, TD=Typical Development, JUA=Job Interview training program using an android robot, IGT=Interview Guidance by Teachers, STEM=Science Technology Engineering Mathematics
Source: Authors.

3.8 Generalization/Maintenance

None of the studies included in the review conducted generalization and/or maintenance probes, so it could not be determined whether the participants retained the skills learned as a part of the intervention or whether the skills were generalized in different settings or circumstances.

3.9 Research rigor

In terms of research rigor, nine studies were rated as having a strong research design, according to the criteria developed by Reichow et al. (2008) (Tables 3 and 4). In group studies, high quality was observed on all primary quality indicators (i.e., participant characteristics, independent variables, comparison situation, dependent variables, link between research question and data analysis, use of statistical tests), and the studies showed evidence of four or more secondary quality indicators (i.e., random assignment, IRA, blind raters, fidelity, attrition, generalization and/or maintenance, effect size, social validity). Of the single-subject studies, one was rated as having a strong, and the other adequate research design.

Table 3. Review of robotic interventions for adolescents and young adults with autism spectrum disorder (ASD): Research quality indicators of group studies

	Quality Indicators														
	Primary Quality Indicators						Secondary Quality Indicators								
Studies	Participant characteristics	Independent variable	Comparison condition	Dependent variable	Link between research question and data analysis	Use of statistical tests	Random assignment	Interobserver agreement	Blind raters	Fidelity	Attrition	Generalization and/or maintenance	Effect size	Social validity	
Kaboski et al. (2014)	HQ	HQ	HQ	HQ	HQ	HQ	NE	NE	NE	E	E	NE	E	E	Strong
Kumazaki, Warren, Corbett et al. (2017)	HQ	HQ	HQ	HQ	HQ	HQ	E	E	NE	NE	E	NE	E	E	Strong
Kumazaki et al. (2018)	HQ	HQ	HQ	HQ	HQ	HQ	E	NE	NE	E	E	NE	E	E	Strong
Kumazaki et al. (2019)	HQ	HQ	HQ	HQ	HQ	HQ	E	NE	NE	E	E	NE	E	E	Strong
kumazaki et al. (2021)	HQ	HQ	HQ	HQ	HQ	HQ	E	NE	NE	E	E	NE	E	E	Strong
Silva et al. (2020)	HQ	HQ	HQ	HQ	HQ	HQ	E	NE	NE	E	E	NE	E	E	Strong
Yoshikawa et al. (2019)	HQ	HQ	HQ	HQ	HQ	HQ	E	E	NE	E	E	NE	E	E	Strong
Yuan et al. (2014)	HQ	HQ	HQ	HQ	HQ	HQ	E	NE	NE	E	E	NE	E	E	Strong

Note. AQ=Acceptable Quality, E=Evidence, HQ=High Quality, NE=No Evidence, UQ=Unacceptable Quality
Source: Authors.

Table 4. Review of robotic interventions for adolescents and young adults with autism spectrum disorder (ASD): Research quality indicators of single-subject studies.

	Quality Indicators												
	Primary Quality Indicators						Secondary Quality Indicators						
Studies	Participant characteristics	Independent variable	Dependent variable	Baseline condition	Visual analysis	Experimental control	Interobserver agreement	Kappa	Fidelity	Blind raters	Generalization and/or maintenance	Social validity	
Jordan et al. (2013)	HQ	HQ	HQ	UQ	HQ	HQ	E	NE	NE	E	NE	E	Strong
Kumazaki, Warren, Muramatsu et al. (2017)	HQ	HQ	HQ	UQ	HQ	HQ	E	NE	NE	NE	NE	E	Adequate

Note. AQ=Acceptable Quality, E=Evidence, HQ=High Quality, NE=No Evidence, UQ=Unacceptable Quality
Source: Authors.

4. Discussion

The main aim of this review was to describe the studies and evaluate their main results related to the effectiveness of the application of robots in interventions for adolescents and young adults with ASD. Ten research papers were selected and analyzed, all of which were published since 2010, and they all included participants in the age range 12-24 years at enrolment.

With regard to the characteristics of the participants, all ten studies included at least one adolescent or young adult with ASD aged 12 to 24 years, and the majority were conducted specifically for ASD; only one study included participants with stroke, cerebral palsy, and Duchenne muscular dystrophy. Four studies included a TD group for comparison. The study participants were mainly male (81%), which should be taken into account in interpretation of the results.

Social skills, the main impairment in individuals with ASD, received the most attention; 4/10 studies conducted interventions related to communication, eye contact, self-disclosure, and social interactions of adolescents and young adults with ASD. Increasing eye contact is thought to be of great importance for individuals with ASD since it is one of the characteristics of nonverbal communication used for social interaction (APA, 2013). Self-disclosure, in which people reveal personal information about themselves to other people, is important in all types and stages of social relationships, and can promote interaction and enhance relationship building (Spretcher et al., 2004; Spretcher et al., 2013).

Overall communication skills, building and maintaining dialogue and communication skills, understanding what others say, conveying thoughts to others, and listening to the thoughts and feelings of others is important in everyday life. Social demands become increasingly complex with maturation (Webb et al., 2004). Adolescents and young adults with ASD, as they grow older, become more conscious of their social difficulties, which may lead to self-limiting of social opportunities. Work-related social skills were targeted in three studies; the employment rate of adults with ASD is quite low (Shattuck et al., 2012), which highlights the need for support, and for identification of tools that can help these people to find and keep employment. Job interviews, which are part of the most common way of finding a job, appear to be a significant barrier for individuals with ASD, because they lack good verbal and/or nonverbal communication skills.

Robots operate within a predictable environment that offers individuals with ASD a structured and safe learning environment, which can be personalized to help them focus on specific stimuli. In addition, Pennisi and colleagues (2015) observed that individuals with ASD show a higher degree of engagement when they communicate with robots than with human teachers. Most of the studies used a humanoid android robot, which has an appearance and movements resembling a real person. An android robot for interventions provides individuals with ASD the opportunity to be exposed to a three-dimensional learning experience that can be programmed to resemble a potential real-life situation in a controlled way. Previous research documented the preference of individuals with ASD for interacting with robots that are less detailed and less visually complex, while still conforming to the humanoid form (Robins et al., 2009). More recent research (Kumazaki, Warren, Muramatsu, et al., 2017) found that individuals with higher levels of reported ASD symptomatology preferred a more complex appearance (i.e., android robots).

The data collection methods used in the studies (i.e., questionnaire, observation, and interview) were human-assisted. These methods are at risk of errors when compared to machine-assisted methods. The number of clicks may be miscounted due to human mistakes, whereas machine-assisted programs minimize this possibility. Humans, however, may observe features not "noticed" by machines. A combination of human-assisted programs, which continue to be ideal for assessing participant behavior, and machine-assisted data collection methods, could be adopted by researchers. Most of the studies were conducted in either a classroom environment or a controlled research environment. The interventions could be replicated in a home environment or in a classroom environment, accordingly, with appropriate support and training of caregivers and parents, in order to support generalization of the targeted skills. The studies used both programming-assisted parameters and human-assisted parameters, and most of the evaluation parameters used require hard effort by humans to analyze and process the recorded data. The tasks the participants perform in each study, and which are recorded by the researchers (e.g., identifying and calculating the numbers of correct or incorrect responses, the number of the attempts, the time spent on each attempt) would be better done by a machine, and the recorded data can then be analyzed by a human. In spite of the importance of the generalization and maintenance of the acquired skills, it was found that no research study in this review had conducted generalization and maintenance phase.

It is apparent from this review that robotic interventions can produce a positive effect on a range of independent living skills, with positive outcomes, including amelioration of ASD symptoms such as repetition, and reduction of social anxiety, and producing an increase in confidence, communication skills, imitation, and eye gaze. Therapists, clinicians, teachers and parents should consider robotics as a promising tool implemented in the interventions for adolescents and young adults with ASD. Positive outcomes of the interventions appear to depend on the type of robot used, the research environment, the intervention procedure, the characteristics of the participants, and the family.

5. Conclusions and Suggestions

This review has several limitations. It included only research articles written in English and published in peer-reviewed journals. Any grey literature has been excluded. Since the keywords "robotics" and "robot" were the only technology-related terms used, this may have narrowed the number of the possible studies, and the search procedure and the strict inclusion and exclusion criteria might have resulted in missed articles. Future research should continue to explore robotics interventions and their impact on adolescents and young adults with ASD, and regural reviews should be conducted to compare the evidence of their effectiveness.

Most of the studies in this review focused on interventions for improvement of social skills (i.e., communication, eye gaze, attention, social interactions, work-related social skills), which are considered to be among the greatest impairments of individuals with ASD. These skills are difficult to teach and to learn, since even slight changes may change the responses (Ayres et al., 2017). Social skills, however, are of particular importance for adolescents and young adults with ASD, since peer groups become more important as they get older. In addition, social skills are related to vocational skills; Chiang and colleagues (2013) found that of 830 secondary school leavers with ASD, those who had a higher level of social skills were more likely to find and maintain employment than those with low social skills.

Given the importance of employment in the life of every individual, it is obvious that future research should focus on work-related social skills to help and enhance the efforts of adolescents and young adults with ASD to find and maintain competitive employment.

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