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Can social robots help children in healthcare contexts? A scoping review

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ABSTRACT

Objective To review research on social robots to help children in healthcare contexts in order to describe the current state of the literature and explore future directions for research and practice.

Design Scoping review.

Data sources Engineering Village, IEEE Xplore, Medline, PsycINFO and Scopus databases were searched up until 10 July 2017. Only publications written in English were considered. Identified publications were initially screened by title and abstract, and the full texts of remaining publications were then subsequently screened.

Eligibility criteria Publications were included if they were journal articles, conference proceedings or conference proceedings published as monographs that described the conceptualisation, development, testing or evaluation of social robots for use with children with any mental or physical health condition or disability. Publications on autism exclusively, robots for use with children without identified health conditions, physically assistive or mechanical robots, non-physical hardware robots and surgical robots were excluded.

Results Seventy-three publications were included in the review, of which 50 included user studies with a range of samples. Most were feasibility studies with small sample sizes, suggesting that the robots were generally accepted. At least 26 different robots were used, with many of these still in development. The most commonly used robot was NAO. The evidence quality was low, with only one randomised controlled trial and a limited number of experimental designs.

Conclusions Social robots hold significant promise and potential to help children in healthcare contexts, but higher quality research is required with experimental designs and larger sample sizes.

What is already known on this topic?

- Many research teams are building robots to help care for the growing ageing population.
- Preliminary studies provide evidence that robots can provide companionship for older people.
- Robots may also be suitable for children in hospital.

What this study hopes to add?

- This review shows that research into companion robots for children in health contexts is increasing.
- Robots are being developed especially for children with disabilities and impairments, hospitalised children and those with chronic health conditions.
- Preliminary feasibility studies are promising but higher quality trials are needed.

INTRODUCTION

Social robots are increasingly being developed, tested and used in healthcare contexts.[1–3] Although in relative infancy, social robotic technology holds the potential to assist the healthcare system, helping to meet high healthcare demands and to enhance and support care.[3 4] Children present unique care needs and social robots may provide a useful platform through which these needs can be met.[1 5] Illness can remove children from their normal social networks and pose challenges for coping with treatment and lifestyle changes. Robots could assist children managing chronic illness through education and encouragement to perform healthy behaviours, help distract children coping with acute medical procedures or provide companionship and comfort. In recent years, there has been considerable interest in the application of social robots to the care of the elderly (eg, see Bemelmans *et al*, Mordoch *et al* and Robinson *et al*[6–8]), and recently a scoping review was published in this area.[9] However, research into the application of social robots to help children in healthcare contexts is at an emergent stage[1 10] and has not yet been reviewed.

This scoping review was thus conducted to investigate how social robots have been used to help children in healthcare contexts, in order to clarify and summarise the current state of the literature and to contribute to the facilitation of ongoing research and potential clinical applications. Specifically, the review aims to determine the types of studies that have been conducted, the health conditions that social robots are used with or intended for use with, the types of robots used, the purposes the robots serve, the effectiveness of the robots, how the area of research has developed over time and the gaps that remain in the research. This is a high-level review summarising the field, and it includes a broad range of study designs. It is not a systematic review and does not focus on a narrow range of quality-assessed studies.

METHODS

A scoping review was conducted that investigated the use of social robots for children in healthcare applications. The research question was 'Can social robots help children in healthcare contexts?'. Guidelines were consulted on conducting systematic scoping reviews.[11] We used an electronic search strategy of relevant databases, but reference lists were not searched. Ethical approval was not required.

Search strategy

Publications were identified through searching the electronic databases of Engineering Village, IEEE Xplore, Medline, PsycINFO and Scopus. The search was limited to publications published in English, published until 10 July 2017. The following search strategy was used in Scopus, and this search pattern was adapted to suit the requirements of each database: ((robot*) AND (hospital* OR health* OR clinic* OR treatment* OR therap* OR patient* OR outpatient* OR rehab*) AND (child* OR pediatric* OR paediatric* OR adolesc* OR teen*) AND NOT (surg*)). Relevant subject headings were selected in each database in addition to the use of keywords, and an age limit of 0–18 years was applied.

Screening

After duplicate records were removed, two authors independently screened the titles, abstracts and keywords against the eligibility criteria. Full texts for the remaining publications were obtained and screened by the same two authors. Any differences were resolved through consultation with a third author.

Eligibility

Publications were included if they were journal articles, conference proceedings or conference proceedings published as monographs, before 10 July 2017, written in English. Book chapters, monographs that were not published conference proceedings and reviews were excluded. Included publications described the conceptualisation, development, testing or evaluation of social robots for children (aged 0–18 years) with any kind of mental or physical health condition or disability. Publications focusing exclusively on autism were excluded as this has been reviewed previously[12 13]; however, publications focusing on the broader classification of neurodevelopmental disorders were included. Publications on preventative health behaviours in children without identified health conditions were excluded, as were publications concerning social robots in the context of normative child development. A social robot was conceptualised as a physical electromechanical entity capable of or perceived as capable of sensing and moving, as well as forming a friendly companionship with humans. Purely physically-assistive mechanical robots and surgical robots were excluded, as well as virtual reality. Publications were not excluded on the basis of methodological quality due to the emergent nature of the field.

Data extraction and synthesis

Data were extracted by two authors (JD and AB) using a predetermined spreadsheet. Variables extracted were study type, country, whether a user study was conducted, study setting, outcomes considered, findings, target population, sample, number and age of participants, type of robot, control of robot and purpose of the robot. Unlike a systematic review, a scoping review does not aim to synthesise evidence but to present a narrative account, and the results are described in sections aligning with the aims.

Patient and public involvement statement

Patients and public were not involved in this review.

RESULTS

Study selection

The initial search produced a total of 4179 results. Once duplicates were removed, 1961 publications remained. Initial screening of the titles and abstracts resulted in a working pool of 520 publications. Titles and abstracts were thoroughly screened according to the full eligibility criteria, resulting in 83 publications for which full texts were obtained. Screening full texts resulted in a final 73 publications (see figure 1 and table 1). Of the 73 publications included, 53 were conference proceedings, six were conference proceedings published as monographs and 14 were journal articles.

Types of studies conducted

Publications consisted of technical development papers alone (n=17), technical development papers with a user study (mostly feasibility studies) (n=17), feasibility studies alone (n=13), experimental designs (n=11), discussion papers (n=4), discussion papers with user study (n=3), single-subject designs (n=2), randomised control trials (RCTs) (n=1), case-studies (n=2), interview/focus group studies (n=1) and study proposals (n=2) (see table 1).

Countries

Twenty-three countries were included (see table 1 and figure 2). Most publications came out of Italy, the Netherlands, or Spain, and some publications included more than one of these countries. This may reflect greater funding or interest in this area of research in these countries compared with elsewhere.

User studies

The majority of publications included a user study (n=50) (table 2), four proposed a user study and four consulted users.

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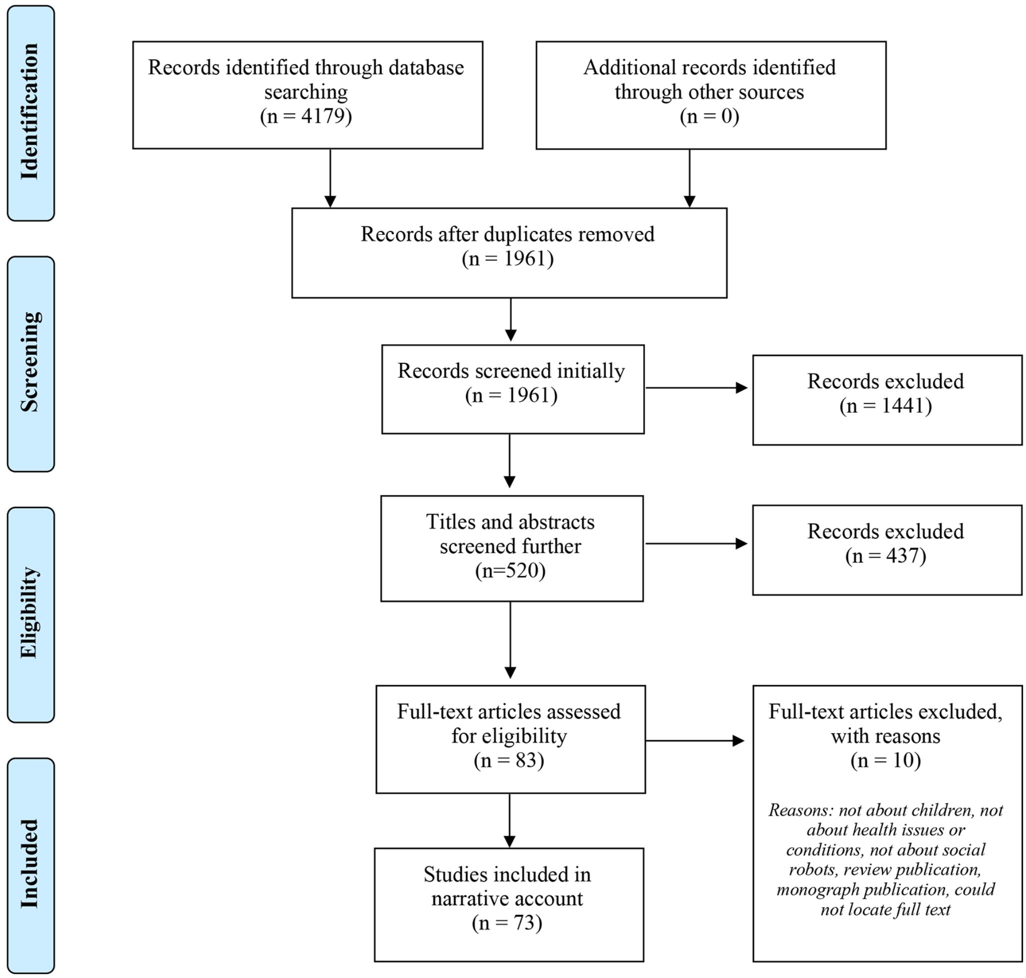

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2009 flow diagram.

Health conditions social robots are used with

Target populations

Disabilities and impairments comprised the largest grouping (n=27) (see table 1). Cerebral palsy featured in nine of these publications, with other identified groups including cognitive, physical and neurodevelopmental disabilities, traumatic brain injury and communication impairments.

Other common target populations were hospitalised children (n=18), diabetes (n=15), cancer (n=3), children attending medical appointments (n=3) and children unable to attend school (n=2). Less common target populations featuring only once included anxiety, myalgic encephalomyelitis, disruptive behaviour problems, users in socially difficult environments and obesity.

Samples

There was considerable overlap between target populations and the samples employed, although children without identified health conditions were sometimes sampled despite not being the target end-users (n=5). In some cases, the sample was described only as 'children' (n=2). The age range varied from 1 to 18 years. The number of participants ranged from 2 to 70 (see figure 3). The majority reported small sample sizes (see table 2).

Setting

Hospitals (n=11), rehabilitation clinics/centres (n=10) and schools (n=7) were the most common settings. Robots that served a telepresence purpose were used across hospitals, homes and schools (n=3). Additional settings included medical centres (n=2), laboratories (n=3), diabetes summer camps (n=2), a clinical training centre (n=1), an institute for cerebral palsy (n=1), a dental clinic (n=1), inpatient and outpatient clinics (n=2) and event days at a university and museum (n=2). In some cases, multiple settings were utilised (n=2) or the setting was not specified (n=4).

Types of robots used

Twenty-six different robots were used (see table 1), ranging in stage of development from concept formulation through to commercially available models. The humanoid NAO robot was the most common (n=29). IROMEC robot was the second most common robot (n=8), used exclusively with children with disabilities and impairments. Some other robots identified were Pleo,

Table 1 Summary of included publications, with authors and country, study type, target population, robot type and purpose (note: n/a = not applicable)

Source and country	Study type	Target population	Robot(s) and source	Purpose of robot
Cheetham *et al*, Canada[33]	Technical development	Hospitalised children	PEBBLES Telbotics Inc (Canada)	Telepresence (connect hospitalised children to their classroom, support academic and social tasks)
Fels *et al*, Canada[34]	Case study	Children who cannot physically attend school	PEBBLES Telbotics Inc (Canada)	Telepresence (connect ill child to school/education, be a physical representation of the child, support academic and social tasks)
Kimura *et al*, Japan[35]	Feasibility study	Hospitalised children	AIBO, Necoro cat, Capriro, and other interactive animal soft-toys Sony (Japan), Omron (Japan), Bandai (Japan)	Companion (improve mood and quality of life)
Goris *et al*, Belgium[36]	Technical development	Hospitalised children	Probo, Prototype	Inform, support, comfort
Looije *et al*, the Netherlands[28]	Experimental design (mixed design)	Diabetes, obesity and coeliac	iCat, Phillips Electronics (the Netherlands)	Motivator, educator, companion/buddy
Saldien *et al*, Belgium[37]	Technical development	Hospitalised children	Probo, Prototype	Entertain, communicate, provide medical assistance
Goris *et al*, Belgium[38]	Technical development	Hospitalised children	Probo, Prototype	Entertain/play, communicate/inform, provide medical assistance/comfort
Marti *et al*, Italy[21]	Technical development and feasibility study	Disabilities (autistic, motor impaired, intellectual disability)	IROMEC, Prototype	Support and stimulate play in educational/therapeutic settings
Marti *et al*, Italy, Austria, Spain, the Netherlands and UK[39]	Technical development	Disabilities (autistic, motor impaired, intellectual disability)	IROMEC, Prototype	Companion (engage child in social interactions, empower discovery of a range of play styles)
Marti *et al*, Italy, Austria, Spain, the Netherlands and UK[40]	Technical development	Disabilities (autistic, motor impaired, intellectual disability)	IROMEC, Prototype	Companion (engage child in social interactions, empower discovery of a range of play styles)
Bernd *et al*, the Netherlands[18]	Single-subject design	Intellectual disabilities	IROMEC, Prototype	Support play in an occupational therapy intervention
Böhm *et al*, Austria[41]	Technical development	Disabilities	IROMEC, Prototype	Support and stimulate play
Saldien *et al*, Belgium[42]	Technical development	Hospitalised children	Probo, Prototype	Interact with hospitalised children
Díaz *et al*, Spain[15]	Feasibility study	Hospitalised children	NAO and Pleo Softbank robotics (Japan), Innvo labs (Hong Kong)	Companion (improve quality of life)
Klein *et al*, the Netherlands[43]	Single-subject design	Developmental disabilities	IROMEC, Prototype	Support play in an occupational therapy intervention
Lehmann *et al*, UK[16]	Experimental design (within subjects)	Cognitive disabilities	KASPAR and IROMEC, Prototype	Engage in play, facilitate social interaction, facilitate cognitive and social development
Lu *et al*, USA[44]	Technical development and feasibility study	Diabetes	Lego Mindstorm NXT Lego (Denmark)	Companion/pet (reduce anxiety and fear)
Ros Espinoza *et al*, Italy[45]	Discussion paper	Diabetes	NAO, Softbank robotics (Japan)	Companion, instructor, playmate (engage child and support self-management, interact with child)
Ros *et al*, Italy[46]	Technical development and feasibility study	Hospitalised children	NAO, Softbank robotics (Japan)	Exercise demonstrator, motivator, companion, help develop social skills
Saint-Aimé *et al*, France[20]	Technical development and feasibility study	Hospitalised children/vulnerable children	Emi, Prototype	Companion (provide comfort)
Csala *et al*, Hungary[47]	Technical development and feasibility study	Hospitalised children (bone-marrow transplant)	NAO, Softbank robotics (Japan)	Companion (provide motivation and joy)
Looije *et al*, the Netherlands[29]	Experimental design (within subjects)	Diabetes and other chronic conditions	NAO, Softbank robotics (Japan)	Education companion
Nalin *et al*, Italy[48]	Discussion paper	Diabetes	n/a	n/a
Barco *et al*, Spain[49]	Study proposal	Traumatic brain injury	LEGO Mindstorm NXT, Lego (Denmark)	Cognitive rehabilitation (run activities, monitor performance), pet
Besio *et al*, Italy[19]	Feasibility study	Disabilities	IROMEC, Prototype	Engage child in play

Continued

Table 1 Continued

Source and country	Study type	Target population	Robot(s) and source	Purpose of robot
Calderita *et al*, Spain[50]	Feasibility study	Upper limb motor deficits (cerebral/brachial plexus palsy)	Ursus, Prototype	Therapy tool (playmate; exercise coach, engagement, measure and record data)
Csala *et al*, Hungary[51]	Feasibility study	Hospitalised children (bone-marrow transplanted)	NAO, Softbank robotics (Japan)	Companion (provide motivation and joy)
De Greef *et al*, theNetherlands[52]	Case study	Diabetes	NAO, Softbank robotics (Japan)	Interact with children
Okita, USA[26]	Experimental design	Hospitalised children	Paro, Paro robots (Japan)	Companion (reduce anxiety and pain)
Ryu *et al*, Korea[53]	Technical development	Children who cannot attend school	Robot under development, Prototype	Telepresence (connect ill child to school/education, reduce social isolation)
Alemi *et al*, Iran[24]	Experimental design	Cancer	NAO, Softbank robotics (Japan)	Therapy assistant (information, reduce distress)
Baroni *et al*, Italy[54]	Interview/focus groups	Diabetes	NAO, Softbank robotics (Japan)	Companion/peer (support and assist self-management)
Calderita *et al*, Spain[55]	Technical development and feasibility study	Neurorehabilitation	THERAPIST, Prototype	Therapy tool (playmate; coach, engagement, measure and record data)
Fridin *et al*, Israel[27]	Technical development and feasibility study	Cerebral palsy	NAO, Softbank robotics (Japan)	Therapy coach/exercise demonstrator (motivation, encouragement, feedback)
Kozyavkin *et al*, Ukraine[56]	Feasibility study	Cerebral palsy	KineTron, Robotis (South Korea)	Exercise demonstrator/coach (motivate and encourage)
Kruijff-Korbayová *et al*, Italy[30]	Experimental design (between subjects)	Diabetes	NAO, Softbank robotics (Japan)	Provide long-term support, improve diabetes self-management
Lewis *et al*, UK[57]	Technical development	Diabetes	NAO, Softbank robotics (Japan)	Improve diabetes management (confront child, bond with child to increase motivation and engagement)
Malik *et al*, Malaysia[58]	Technical development and study proposal	Cerebral palsy	NAO, Softbank robotics (Japan)	Therapy tool (exercise demonstrator, motivator, companion to improve quality of life)
Malik *et al*, Malaysia[59]	Study proposal	Cerebral palsy	NAO, Softbank robotics (Japan)	Therapy tool (exercise demonstration, motivation, companion)
Messias *et al*, Portugal[60]	Technical development	Hospitalised children	MOnarCH, Prototype	Edutainment
Özkul *et al*, Turkey[61]	Technical development and feasibility study	Communication impaired	NAO and Robovie, Softbank robotics (Japan), Vstone Ltd (Japan)	Social peer/assistant (motivate, evaluate effort, give feedback, improve learning and recognition rate)
Vélez *et al*, Ecuador[62]	Technical development and feasibility study	Learning and psychosocial disabilities	ROBSNA, Prototype	Interact with children, stimulate play, support special education processes
Albo-Canals *et al*, Spain[63]	Technical development and feasibility study	Hospitalised children	Pleo, Innvo labs (Hong Kong)	Companion (reduce anxiety and stress)
Alotaibi *et al*, Saudi Arabia[64]	Technical development	Diabetes	Aisoyl V5 Robot, Aisoy Robotics (Spain)	Improve diabetes management (educate/give advice, motivate, monitor, companion)
Gonçalves *et al*, Portugal[65]	Technical development	Hospitalised children	MOnarCH Prototype	Interact with hospitalised children
Jeong *et al*, USA[66]	Experimental design	Hospitalised children	Huggable, Prototype	Mitigate stress, anxiety, pain
Köse *et al*, Turkey[67]	Feasibility study	Communication impaired	Robovie, Vstone Ltd (Japan)	Social peer/assistant (motivate, evaluate effort, give feedback, improve learning and recognition rate)
McCarthy *et al*, Australia[68]	Technical development and study proposal	Rehabilitation	NAO, Softbank robotics (Japan)	Exercise demonstrator, motivator, distractor, monitoring aid
Rabbitt *et al*, USA[31]	Experimental design	Disruptive behaviour problems	n/a	Administer cognitively based treatment
Rahman *et al*, Malaysia[69]	Feasibility study	Cerebral palsy	NAO, Softbank robotics (Japan)	Exercise demonstrator (motivate and encourage)
Alemi *et al*, Iran[25]	Experimental design	Cancer	NAO, Softbank robotics (Japan)	Therapy assistant (provide information, reduce distress)

Continued

Table 1 Continued

Source and country	Study type	Target population	Robot(s) and source	Purpose of robot
Al-Taee *et al*, UK[70]	Feasibility study	Diabetes	NAO, Softbank robotics (Japan)	Diabetes management (educate, motivate, monitor, companion)
Arnold, USA[71]	Technical development	Anxiety	Emobie, Prototype	Companion, communication between children, parents, therapists
Bonarini *et al*, Italy[72]	Technical development and feasibility study	Neurodevelopmental disorders	Teo, Prototype	Therapy-driven game-based activities; free play
Børsting *et al*, Norway[73]	Feasibility study	Myalgic encephalomyelitis/ chronic fatigue syndrome	Robot-avatars, Prototype	Telepresence (connect ill child to school/education, reduce social isolation, be a physical representation of the child)
Cañamero *et al*, Italy[74]	Discussion paper	Diabetes	NAO, Softbank robotics (Japan)	Improve diabetes management (educate/give advice, motivate, monitor, companion)
Díaz-Boladeras *et al*, Spain[75]	Technical development and feasibility study	Hospitalised children	Pleo, Innvo labs (Hong Kong)	Companion (alleviate anxiety, loneliness, stress)
Larriba *et al*, Spain[22]	Technical development	Hospitalised children	Pleo, Innvo labs (Hong Kong)	Reduce pain and anxiety during hospitalisation
Looije *et al*, the Netherlands[17]	Feasibility study	Diabetes	NAO, Softbank robotics (Japan)	Self-management, educational activities, interact with child
Malik *et al*, Malaysia[76]	Feasibility study	Cerebral palsy	NAO, Softbank robotics (Japan)	Therapy coach/exercise demonstrator (motivation)
Martí Carillo *et al*, Australia[23]	Feasibility study	Cerebral palsy	NAO, Softbank robotics (Japan)	Exercise demonstrator; motivator, companion
Meghdari *et al*, Iran[77]	Technical development	Cancer	Dr Arash, Prototype	Interact with hospitalised children and improve quality of life
Neerincx *et al*, Italy and the Netherlands[78]	Feasibility study	Diabetes	NAO, Softbank robotics (Japan)	Improve diabetes management
Robles-Bykbaev *et al*, Ecuador[79]	Technical development and experimental design	Disabilities and communication disorders	SPELTRA, Prototype	Speech-language therapy tool (exercises, recreational activities, register patient information and results, remote support)
Sequeira *et al*, Portugal[80]	Discussion paper	Socially difficult environments	MOnarCH, Prototype	Edutainment
Swift-Spong *et al*, USA[32]	Experimental design	Overweight	NAO, Softbank robotics (Japan)	Exercise buddy
Ullrich *et al*, Germany[81]	Technical development and interview/focus groups	Children in waiting room prior to medical visit	NAO, Softbank robotics (Japan)	Companion (stimulation, empathy, positive coping)
Yasemin *et al*, Turkey[82]	Experimental design	Dental	IRobi, Yujin Robot (South Korea)	Distract, entertain, relax, reduce anxiety and pain
Blanson Henkemans *et al*, the Netherlands[83]	Discussion paper	Diabetes	NAO, Softbank robotics (Japan)	Improve self-management, interact with children in educational activities, provide emotional support
Blanson Henkemans *et al*, the Netherlands[14]	Randomised controlled trial (between subjects)	Diabetes and other chronic diseases	NAO, Softbank robotics (Japan)	Improve diabetes management (education, educate, provide pleasure, motivate)
Gelsomini *et al*, Italy[84]	Technical development	Neurodevelopmental disorders	Puffy, Prototype	Companion (support education and therapeutic interventions, provide multisensory experience)
Martí Carillo *et al*, Australia[85]	Technical development and feasibility study	Cerebral palsy	NAO, Softbank robotics (Japan)	Therapy tool (exercise demonstration, motivation, companion)
Van den Heuvel *et al*, the Netherlands[86]	Feasibility study	Physical disabilities	IROMEC, Prototype	Support play

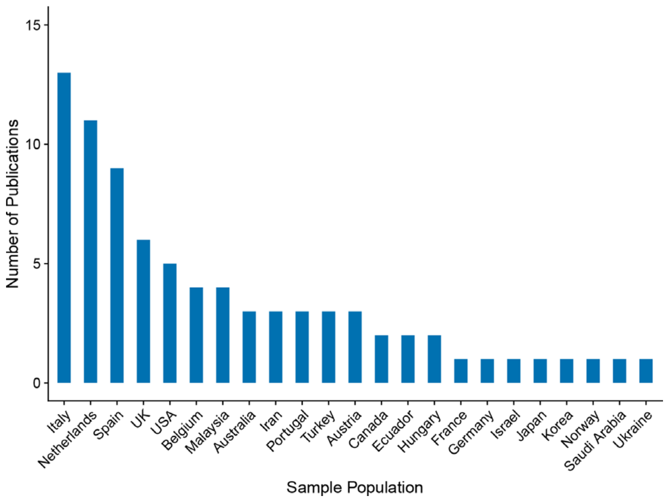

Figure 2 Number of publications by country.

Probo, Robovie, MOnarCH and Paro. Some robots had 'Full' control (no human operator; n=6), 'Goal-based' control (an operator sets a goal but the robot achieves this on its own; n=8), 'None' (no control; n=15) or a combination (n=16). In some cases, control was 'Unknown' (unspecified; n=25) or not applicable (n=2). In one case, the intended level of control was full, but was not implemented (n=1). A distinction was made between on-site (n=27) and off-site (n=6) control.

Purposes the robots serve

The purpose of the robots (see table 1) was most notably to act as a companion, provide comfort, reduce anxiety, pain and distress, express empathy and increase motivation and joy. In some cases, the role was to provide entertainment and/or distraction or be a buddy/peer. Generally, companion robots shared an overarching aim of improving quality of life.

A further purpose was to teach and coach. This involved informational tasks, for example, information provision, exercise demonstration and feedback delivery, as well as more social tasks, for example, providing motivation, encouragement and support throughout teaching. Exercise demonstration was commonly used when the target population was cerebral palsy and was intended to improve physical functioning (n=9). Information provision was more commonly used to help children with diabetes and contribute to disease self-management (n=9).

Another broad purpose was a therapy tool or assistant. In some cases, the robot-administered therapy (both physical and cognitive), but in most cases, the robot was used in conjunction with a therapist and therapy tools. The robots were often used to engage the child in sessions, provide encouragement and stimulate play and social interactions. In some cases, the robots measured, monitored and recorded data.

In four publications, the purpose of the robot was telepresence. This involved connecting an unwell child to school, supporting educational and social tasks, and in some cases, providing a physical representation of the child in the classroom.

Effectiveness of the robots

Outcomes considered

Outcomes most frequently considered were acceptability, perceptions of the robot, user evaluations, implementation, engagement and observations of the child–robot interaction; thus reflecting the early stage of research (see table 2). Some publications explored users' emotions, for example, anxiety, stress, depression, pain and anger, while others considered physical functioning or performance on learning tasks (eg, number of correct diabetes quiz questions). Other specific outcomes included adherence to a nutritional diary, subjective assessment by a therapist, level of playfulness, neuropsychological performance, communication behaviours, heart rate, satisfaction and enjoyment, empathy, academic performance, the role of the robot in the interaction and challenges encountered.

Findings and conclusions

Most publications reported positive outcomes, including generally high acceptance and liking by children, parents, medical staff, teachers and bystanders. However, these results should be treated cautiously given the predominance of subjective and qualitative data (see table 2).

There was only one RCT,[14] conducted with children who had diabetes, which compared the use of a personal robot, a neutral robot and standard care. Diabetes knowledge significantly improved in both robot groups compared with the control group. The personalised robot group scored higher on self-determination theory determinants, rated the robot as more pleasurable, answered more diabetes quiz questions correctly, were more engaged and were more motivated to play the quiz again, compared with the neutral robot group. This finding that personalisation enhanced the interaction was reflected in other publications. For example, different robots can elicit different roles in the user,[15] users express different preferences to certain robots[15 16] and different user profiles can be developed to improve child–robot interactions.[17] The few publications that reported negative findings suggested that the robot did not successfully meet the needs of the children and that better matching was required.[18 19]

Although most publications reported positive outcomes, one study[20] found the child–robot interaction to be negative, suggesting that the robot encounter was stressful. Changes to the study protocol (eg, introducing the child to the robot in a group context rather than alone) were suggested to resolve this issue.

Some publications explored implementability and technical functioning, identifying challenges including time and assistance required by a therapist, the robot falling over and halting interaction and difficulty with speech interpretation.[21–23] A predominant conclusion drawn was

Table 2 Results from user studies included in the review, including participant details, outcome studied and findings (note: n/a = not applicable)

Source	Sample; participant number; age*	Outcomes considered	Findings/conclusions
Cheetham *et al*[33]	n/a (reported elsewhere)	Robot implementability; user evaluation; technical issues	Robots successful in providing telepresence; some technical issues
Fels *et al*[34]	Chronic renal failure; n=3; 9–12 years	Behavioural outcomes (communication, concentration, initiative); perceptions of the robot (by children, parents, and staff); academic performance	Communication and initiative behaviours occurred at high frequencies for short durations, concentration behaviours remained consistently high; trend towards less communication interactions over time; most reported positive perceptions of robot
Kimura *et al*[35]	Hospitalised children; unknown; 1–19 years	Children's mood; how children interacted with robot; human companion in the interaction; user evaluation; communications between staff, children and parents	Children's mood improved; human companion enhanced the child–robot interaction; communications between inpatient children and staff increased
Looije *et al*[28]	Children without identified health conditions; n=24 (20); 8–9 years	User evaluation (fun, acceptance, empathy, trust); performance (efficiency, learning effect)	Children valued physical and virtual iCat more than text interface, interacted faster with iCat character compared with text interface; All interfaces rated highly; Suggests iCat useful to implement and test
Marti *et al*[21]	Disabilities; n=5; 6–11 years	Usability; acceptability; suitability to achieve learning objectives	Children were interested in engaging with robot and understood tasks; several technical issues; robot played a different role in group vs. individual sessions and stimulated different interactions; Robot not perceived as a social agent due to its functional design
Bernd *et al*[18]	Intellectual disabilities; n=3; 3–5 years	Playfulness of children; children's functioning; user evaluation (by the therapists)	Playfulness scores varied—no significant difference between robot and traditional therapy sessions; robot evaluation scores both increased (2/3 children), and decreased (1/3); Therapist evaluations suggested robot appreciated by therapist and children, robot added value but better matching to children's needs required
Díaz *et al*[15]	Children without identified health conditions; n=37†; 11–12 years	Children's interaction with the robots (attitudes, preferences, behaviours, attributions and roles)	Robot features effect children's preferences, perceptions and expectations, which influences their interactions via role attribution; different responses were elicited for each robot: appearance and purpose of robot should be considered during design
Klein *et al*[43]	Developmental disabilities; n=3; 3–5 years	Playfulness of child; functional behaviour of child; subjective assessment of the robot by the therapist	Robot partly met needs of the children and therapists; positive impact on play found for two children; robot may be useful in supporting children with developmental disabilities by enriching play, but long-term effect unknown
Lehmann *et al*[16]	Cognitive and social disabilities; n=10; average 8.3 years	Educational objectives achieved by the children; comparison of the interactions with different robots	Only preliminary analyses presented: robots appear to have positive influence on development; preferences and level of success for the different play scenarios and robots differed by child; potential for robots as therapeutic tools
Lu *et al*[44]	Unknown; unknown; 3–7 years	Children's enjoyment of robot companion	n/a (study not completed)

Continued

Table 2 Continued

Source	Sample; participant number; age*	Outcomes considered	Findings/conclusions
Ros Espinoza *et al*[45]	Diabetes; N and age reported elsewhere	Discusses observations, challenges and lessons learnt from previous studies	Child–robot studies require careful thought
Ros *et al*[46]	Diabetes; n=2; 7 and 11 years	Observations of the child–robot interactions	Robot should be designed to adapt to user's capabilities; children enjoyed the robot
Saint-Aimé *et al*[20]	Children without identified health conditions; n=13; 3–5 years	Quality of the child–robot interaction	Robot did not achieve companion goal; encounter may have been stressful; questionnaire data contradicted observational data; suggested improvements for robot and study protocol
Csala *et al*[47]	Hospitalised children; n=3; 4–14 years	Could robot be implemented; acceptance of robot; user evaluation of the robot	Robot accepted by the children, positive feedback from children, staff and parents; robot appropriate for environment; suggested improvements
Looije *et al*[29]	Children without identified health conditions; n=11 (10); average 11.1 years	Learning/performance; attention; motivation	No differences between robot and virtual agent on learning task or motivation; robot attracted more attention than virtual agent, preferred by the children; robot has potential as learning companion
Besio *et al*[19]	Cerebral palsy; n=4; 4–8 years	Prompts provided by therapist during the child–robot interaction (intensity, type, goal)	Number of prompts to help child understand how to play with robot decreased across sessions; prompts for playfulness and engaging the child remained constant; suggests robot not of added value in therapy, as robot did not meet play needs of the children
Calderita *et al*[50]	Upper limb motor deficits; n=6; 3–7 years	Motor function; satisfaction (of child); acceptability of the robot/user evaluation (from children, parents and staff)	Only preliminary results presented: physical appearance of robot satisfactory; children found sessions enjoyable and motivating; staff found sessions positive and recorded data was useful; a high level of engagement achieved, with motivation and adherence to treatment maintained
Csala *et al*[51]	Hospitalised children; unknown N and age	n/a	Initial feedback positive
De Greef *et al*[52]	Hospitalised children; n=13; 7–11 years	Interaction and engagement with the robot; preferences of activities to engage in with the robot	Only preliminary results presented: typically children were engaged with the robot; children had varying approaches to switching between activities
Okita[26]	Hospitalised children; n=36; 6–16 years	Pain ratings (by child, and by parent); children's and parents' anxiety (positive and negative emotional traits)	Greater decreases in pain and anxiety for children who interacted with the robot together with their parents than those without their parents
Alemi *et al*[24]	Cancer; n=11 (6); 6–10 years	Anxiety; anger; depression,	Children in experimental group had reductions in anxiety, anger and depression compared with control
Baroni *et al*[54]	Diabetes; n=70; 9–13 years	Suggestions from children with diabetes, siblings and parents about how robot could provide support	Robot used for entertainment, self-management support, knowledge, increasing self-confidence and motivation, as a sensitive listener, and to attract attention

Continued

Table 2 Continued

Source	Sample; participant number; age*	Outcomes considered	Findings/conclusions
Calderita *et al*[55]	Children without identified health conditions; n=35; 4–9 years	Perception of the robot as a social entity or artificial machine (by child); robot behaviour and attitude (by independent observer); observations of the interaction	Children perceived robot as a social rather than artificial entity; interaction was usually fluent; enjoyment and neutral states were the most frequently displayed, with boredom present at the beginning of sessions; most of the time children played with robot
Fridin *et al*[27]	Cerebral palsy and children without identified health conditions; n=25 (23); mean age 5.7 (cerebral palsy); 3.3 years (without identified conditions)	Interaction level; motor performance	Children with cerebral palsy had higher interaction level with the robot but worse motor performance compared with typically developing children; robot was feasible for use with pre-school aged children, able to engage and motivate children with cerebral palsy to engage in exercises
Kozyavkin *et al*[56]	Cerebral palsy; n=6; 4–9 years	User evaluation of the robot (via interview with children and their parents)	All children liked rehabilitation sessions with the robot and would like it in future sessions; suggestions for improvement offered by parents
Kruijff-Korbayová *et al*[30]	Diabetes; n=59; 11–14 years	Effect of off-activity talk (OAT) on perception of the robot, interest in further engagement and adherence to nutritional diary	No effect of OAT on children's perception of robot or adherence to nutritional diary; OAT and NOAT conditions combined had increased adherence compared with control condition; OAT condition more interested to have another session with robot compared with no OAT condition
Özkul *et al*[61]	Hearing impaired; n=31; 7–16 years	Recognition rate/error rate by platform and sign, user evaluation	Some differences between preferred robot; some signs were better recognised than others; children with different levels of hearing impairment and sign language ability were motivated to play the games; Support for use of game to increase recognition rate
Vélez *et al*[62]	Children (non-specified); n=3; 3–6 years	Empathy and apathy level (specifically by measuring aspect, voice and movements)	Child–robot interaction in all cases manifested as empathy (not apathy), suggested children found the robot appearance likeable
Albo-Canals *et al*[63]	Unknown	n/a	Enhancing child–robot interaction engagement through cloud connectivity can improve use of robot in treatment
Jeong *et al*[66]	Hospitalised children; n=4; 5–10 years	Behaviours of children and parents during robot and virtual character interactions	Preliminary qualitative results suggest preference for robot but more data and analyses required
Köse *et al*[67]	Hearing impaired; n=31; 7–16 years	Recognition rate/error rate by platform and sign; user evaluation	Some differences between preferred robot; some signs better recognised than others; children with different levels of hearing impairment and sign language ability were motivated to play with robots; physical embodiment of robot can improve children's performance, engagement and motivation
Rahman *et al*[69]	Cerebral palsy; n=2; 9 and 13 years	Clinical experiences; challenges encountered	Potential for use of robot in rehabilitation; challenges identified (eg, difficulty for the robot in interpreting child with speech impediment, need for therapist assistance, etc)

Continued

Table 2 Continued

Source	Sample; participant number; age*	Outcomes considered	Findings/conclusions
Alemi *et al*[25]	Cancer; n=11 (10); 7–12 years	Anxiety; anger; depression	Children in the experimental group showed reductions in anxiety, anger and depression, compared with control
Al-Taee *et al*[70]	Diabetes; n=37; 6–16 years	Acceptability of robot; user evaluation of the robot (what features were desirable)	Robot accepted by patients and parents, some differences between age groups; ability for blood glucose advice was desirable; companion function was less desirable
Bonarini *et al*[72]	Neurodevelopmental disorders; n=11†; 3 years and 6–10 years	Observed behaviours/responses of the children	Preliminary support that robot elicits social interaction, operational behaviours and emotional responses and robot may be integrated into neurodevelopmental disorder therapy
Børsting *et al*[73]	Myalgic encephalomyelitis/chronic fatigue syndrome; n=9 (2); 12–16 years	Access to school and social participation; robot implementation; user evaluation of robot (with children, parents and teachers)	Generally positive feedback provided, suggested robot could connect child to school and social relations; some technical issues
Cañamero *et al*[74]	Diabetes; n=17; unknown age	Discusses user evaluation and implementability	Initial pilot interactions positive
Díaz-Boladeras *et al*[75]	Inpatient and outpatient children; n=unknown†; 2–13 years	Implementation of the robot; interactions with the robot; user evaluation of the robot	Robot found to mediate and facilitate interactions between different participants; Robot took on role of distractor, toy and companion
Larriba *et al*[22]	Hospitalised children; unknown N and age	Technical functioning of the robot; observations of the robot interactions	Wireless communication between robot and Android device was achieved; some issues remain (eg, lack of robustness and reactivity)
Looije *et al*[17]	Diabetes; n=17; 6–10 years	Evaluation of the robot and scenarios used; how the child interacted with the robot; perceptions of the robot (from children, parents, medical staff)	Children, parents, and medical staff had positive experiences with robot; five user profiles were derived to aid further personalisation; conclusive evidence from analysis of specific metrics was not found
Malik *et al*[76]	Cerebral palsy; n=2; 5 and 14 years	Gross motor functional measurement, time up and go and trail making test tests; human–robot interaction attention	Only preliminary results presented: suggests children demonstrated positive responses; study contributed a measurement for attention during human-robot interaction
Martí Carillo *et al*[23]	Cerebral palsy	Time costs (eg, how long it took to position the robot, place auxiliary aids, help robot keep pace); implementation	Some time costs and issues; physiotherapists willing to implement the robot; patients seemed engaged
Neerincx *et al*[78]	Diabetes; n=3, unknown, n=55†; 10–14 years and 8–11 years	Words and behaviours that indicate sentiment and emotion of Dutch and Italian children	Children responded positively to the robot; some cultural differences observed; highlights need for robot to accommodate cultural differences
Robles-Bykbaev *et al*[79]	Cerebral palsy and communication disorders; n=29; unknown age	Performance in phonological, morphological and semantic areas of speech therapy	Children adapted quickly to the robot; children in robot group scored better in phonological area than control group; similar results observed in the morphological and semantic areas too, but not statistically significant

Continued

Table 2 Continued

Source	Sample; participant number; age*	Outcomes considered	Findings/conclusions
Sequeira *et al*[80]	Hospitalised children; unknown N and age	Robot integration into environment; human–robot interaction; acceptability; user evaluation (children, staff, parents, visitors)	Acceptance of the robot was high; suggests that social robots may be positively used in socially difficult environments
Swift-Spong *et al*[32]	Overweight; n=22 (18); 11–14 years	Enjoyment of physical activity; intrinsic motivation for physical activity; activity levels; user evaluation (reactions to the robot back stories); other measures not discussed in this paper	No differences found between robot with different backstories; participants reacted positively to the robot as exercise buddy; no differences in preintervention and postintervention assessments, although trend towards increased intrinsic motivation was observed
Yasemin *et al*[82]	Dental; n=33; 4–10 years	Heart rate; affect; treatment willingness	Only preliminary results presented: suggests anxiety and pain during dental treatment was reduced by robot
Blanson Henkemans *et al*[14]	Diabetes; n=27; 7–14 years	Self-determination determinants (autonomy, competence, relatedness); pleasure; motivation to play quiz; diabetes knowledge; engagement with robot	Diabetes knowledge improved in both robot groups compared with control; personalised robot group higher on self-determination theory determinants, rated robot more pleasurable, answered more diabetes questions correctly, more engaged, more motivated to play the quiz compared with neutral robot group
Martí Carillo *et al*[85]	Cerebral palsy; n=39†; unknown and 3–16 years	Phase 1: roles, requirements and acceptability of the robot; phase 2: robot performance/fulfilment of system requirements; perceptions of robot; therapeutic benefit	Phase 1: effective uses of robot established; key roles determined; observations of patients indicated improved compliance with therapist instructions and increased motivation with robot; phase 2: ongoing
Van den Heuvel *et al*[86]	Physical disabilities; n=11; 18 months–19 years	Effectiveness of assistive technology; level of playfulness; user evaluation; feasibility; usability; barriers	Robot had positive effect on achieving predetermined goals; children evaluated the interaction positively; playfulness slightly increased; several usability/technical issues identified (eg, instability of the robot).

*Entries with an †indicate there were multiple studies published in the publication. Numbers in brackets are the number of participants that were analysed.

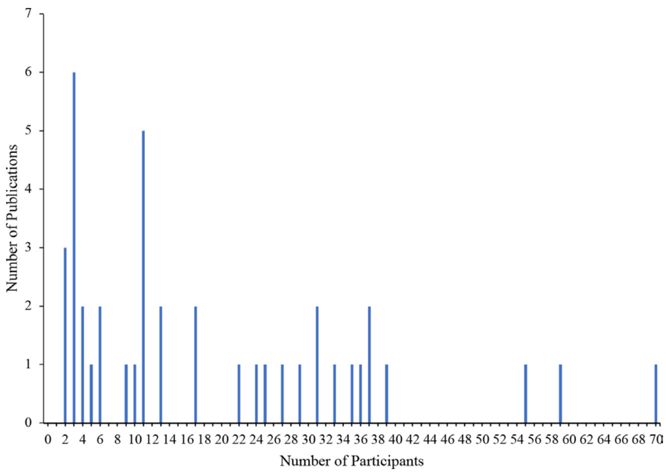

Figure 3 Number of participants in user studies by number of publications.

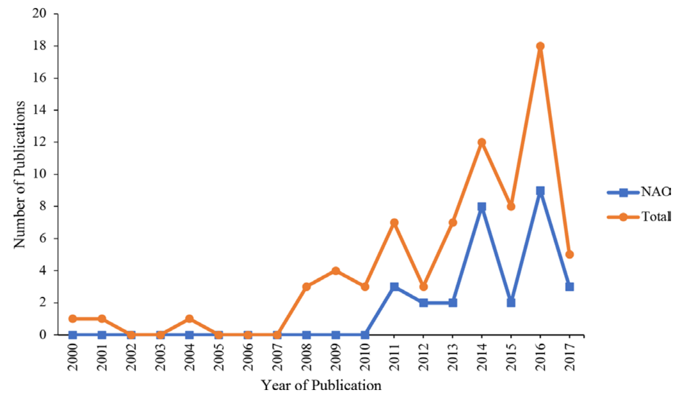

Figure 4 Number of publications by year of publication.

that further development and testing of the robots was required.

Several studies employed statistical significance testing, and the results are described below. These studies, as well as other non-statistical studies, may help generate more specific hypotheses to be investigated in future controlled study designs, but do not necessarily in and of themselves provide evidence of benefit. One study showed significant reductions in anxiety, anger and depression in patients with cancer in a social robot-assisted therapy group compared with a psychotherapy (control) group.[24 25] In other work, hospitalised children who interacted with a robot together with their parent demonstrated greater decreases in pain and anxiety compared with those who interacted with the robot alone.[26] Children with cerebral palsy had a significantly higher interaction level with an exercise demonstration robot (although worse motor performance) than typically developing children, demonstrating the feasibility of the robot for use as a motivating and engaging therapeutic tool.[27] Children interacted significantly faster with robot characters than with a text interface and significantly valued the robot characters more.[28] In a related study, children displayed no differences in performance of a learning task or motivation levels when comparing their use of a physical robot or virtual robot, however, the physical robot attracted more attention than the virtual agent and was preferred.[29] Robot interactions increased adherence to a nutritional diary compared with a no-robot condition among children with diabetes.[30] An online survey about hypothetical robot therapy for children with disruptive behavioural problems found that while the treatment was considered more acceptable than no treatment, it was less acceptable than internet-based treatment.[31] Other publications conducted significance testing, but did not find significant effects.[18 32]

How research has developed over time

The number of publications per year has increased from 2000 to 2017, as shown in figure 4 (note, only part of 2017 is included in the review). Four experimental studies were published prior to 2014 and seven were published from 2014 onwards; the randomised trial was published in 2017. This suggests that more robust research methods have been employed over time.

DISCUSSION

Summary of evidence

This review identified 73 studies that explored the use of social robots for children in healthcare applications. Robots were used to serve a range of purposes, including a companion role, teacher/coach, to connect unwell children to school and to assist in therapeutic and educational endeavours. The wide range of target populations highlights many potential applications, in particular for children with disabilities, impairments, and diabetes, who require intensive ongoing care. Although hospitalisation is not necessarily long term, anxiety, pain and distress are often heightened during hospitalisation. There are potential benefits of using social robots if they can help reduce burden in all three of these contexts. Some of the key findings suggest that social robots can help children with diabetes to improve knowledge; reduce anxiety, anger and depression in children with cancer, and engage children with cerebral palsy in exercises to help improve physical functioning.

The humanoid NAO robot was the most widely used, likely due to its commercial availability, ability to be personalised and relatively autonomous capabilities. Its size and appearance makes it appropriate and appealing. The level of control of robots ranged from almost fully autonomous, to entirely controlled by a human operator. There is a clear need for technological developments to increase the autonomy of all of the robots, particularly in speech recognition and speech production.

Limitations

While the publications provide support for the use of social robots to help children in healthcare, the quality of the evidence is low, which represents a significant limitation. Specifically, the lack of RCTs and the minimal number of experimental designs hinder the formation of firm conclusions about efficacy and effectiveness. It is difficult to determine whether the positive outcomes observed are due to the actions of the robot or some other extraneous variables. For example, the novelty effect of robots must be considered as well as additional attention from researchers or therapists. With longer-term use of robots and increased exposure and integration of robots into society, it is unclear whether the benefits proposed from these early studies will continue, as children may no longer be as easily engaged, motivated, distracted and entertained by this technology.

At the review methodology level, a limitation is that the reference lists of publications were not checked to identify other relevant studies. In addition, papers were limited to the English language, which may have resulted in some missed publications. Formal quality assessment of studies was not performed because scoping studies do not typically aim to assess quality of evidence.

Gaps in the research

A number of gaps exist in research to date. First, more robust methods need to be employed including experiments and randomised trials with larger sample sizes. Second, the effects of humans on the child–robot interaction requires further RCT exploration. Most of the publications did not explicitly comment on the role of humans in facilitating the child–robot interaction, but of those that did, it appears that humans play a key role in influencing the success and outcomes of the interaction. Third, cultural aspects could be considered, as the majority of research has been conducted in Europe, the UK and the USA. The research paradigm is largely from the perspective of human–robot interaction, with the aim to develop and test robots using small feasibility studies, with subjective reports of acceptability the most common outcome. Research is moving towards experimental designs and more robust health outcomes must be included. Future research will benefit from integrating a stronger healthcare perspective.

Implications for practice

At present, robots should be considered as adjunctive, rather than as replacements for human care roles. To date, there is insufficient evidence for further practice recommendations to be made.

CONCLUSION

The results highlight the significant promise and potential held by social robots to help children in healthcare, but demonstrate the need for more and higher quality research. In particular, more RCTs, experimental designs and longer-terms studies are required, with larger sample sizes. There is considerable excitement surrounding the use of robotics in healthcare, but there remains a long way to go in terms of technological developments, integration into the healthcare system and establishment of effectiveness.

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