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Social robot interventions for child healthcare: A systematic review of the literature

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ABSTRACT

Background: We present a systematic review of the literature on social robot interventions for child healthcare. The primary features and outcomes of studies using social robots are illustrated, to advance our comprehension towards the development of useful and effective social robot-based health interventions for the children.
Methods: We conducted a literature search in the bibliographic databases of PubMed and Scopus in order to find studies incorporating social robot interventions targeting child healthcare. The studies were synthesized according to the intervention's target, main robot features, study design, target age of children, number of participants, follow-up duration, and primary outcomes.
Results: Our review reveals that most studies involved only a single session of interactions with the robot, and conducted with a limited number of participants. The interventions targeted alleviation of distress in children with cancer, exercise coaching, improvement of playfulness in children with intellectual disabilities, improvement of mental health, reduction of pain and distress in pediatric inpatient or outpatient settings, e.g., during needle insertions or vaccination, improvement of nutritional knowledge, and achievement of instant therapeutic or education goals in children with physical disabilities. The majority of the studies (85%) reported significant outcomes in technology acceptance, feasibility, enjoyment, engagement, achievement of therapeutic/education goals, pain, and mental health outcomes.
Conclusion: Significant outcomes in the mental state of children, suggest that social robots should be considered in the design of psychological interventions for children. More rigorous research in the area of evaluation of social robot interventions for child healthcare is warranted.

1. Introduction

Social robots have recently attracted the interest of the research community, towards the advancement of digital health [1,2]. In contrast to other modalities of digital health, such as mobile applications and virtual agents, social robots provide engagement with the physical world and enable natural interactions with humans, e.g., through voice, gestures, or touch [3]. As a result, social robots are likely to promote interactive guidance, education, and motivation, which are important enablers for effective management or prevention of diseases.

It is widely recognized that social robots and their interactive features are well accepted by children [4,5]. Therefore, the use of social robots by children, emerges as a reasonable approach towards supporting them and improving their health. The acceptability, potential, and value of social robots in child healthcare has been found in a number of previous studies [6–8].

Review studies in the area of social robots for child healthcare have been remarkably limited. Related reviews have not focused on pragmatic studies providing quantitative outcomes [9], or underlined the application of social robots in a single disease such as diabetes [10], or disorder such as autism [11]. Other reviews for social robots have not specifically focused on child healthcare [3,12], which is considered to be essential, because children have unique care needs.

Given the significance of social robots in child healthcare and their virtue in the provision of future digital health services, we wanted to assess the progress made in the application of social robot-based interventions. To this end, we conducted a systematic review of the literature, aiming to demonstrate the features and outcomes of social robot-based interventions in child healthcare, as assessed in pragmatic studies. The primary goal of this review is to advance our comprehension towards the development of the next-generation of digital health services through the employment of useful and effective social robot-

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based health interventions for children.

2. Methodology

We searched the widely-used bibliographic databases of Scopus and PubMed to identify recent studies published over a 12-year period (2010–2022), utilizing social robots within digital health interventions. The inclusion criteria for study selection were the following: a) the study should be conducted with children or adolescents till the age of 18 years, b) the use of a social robot for healthcare purposes should be described, c) quantitative outcomes of a pragmatic study should be presented, and d) the paper describing the study, must have been written in English. Ongoing studies, case reports, simulation studies, surveys or reviews, qualitative studies, studies describing protocols, studies targeting children diagnosed with autism, and all studies conducted before 2010 were excluded from the review. We chose to exclude studies targeting autism, because these involve a special category of interventions, for which related reviews already exist [11]. Nevertheless, studies focusing broadly on neurodevelopmental disorders were included.

Searches of the electronic databases were initially conducted in April 2020, and an updated search was conducted on April 2023. We used the following terms for our literature search within the title, abstract, and keywords of the manuscripts: *"robot" AND ("child" OR "childhood" OR "adolescent" OR "adolescence") AND ("health" OR "well-being" OR "medical" OR "treatment" OR "care")*. Two authors (AT, AA) independently screened the papers, in order to eliminate possible errors or bias in the selection process. All abstracts of the found articles were assessed for their eligibility according to the inclusion and exclusion criteria. The final papers for inclusion in the review were selected after reading the full manuscripts of the eligible articles.

We adopted the Effective Public Health Practice Project (EPHPP) tool to assess the methodological quality of the studies, based on the six criteria for participant selection bias, study design, confounders handling, blinding of participants and researchers, data collection methods, and withdrawals or dropouts. We used EPHPP because it has been largely used in review studies and it has demonstrated reliability [13]. Guidelines for the tool[1] indicate that for each quality criterion, a rating of weak, moderate, or strong is applied. For example, for selection bias a strong rating is applied when the selected individuals are very likely to be representative of the target population and there is greater than 80% participation; a moderate rating is applied when the selected individuals are at least somewhat likely to be representative of the target population and there is 60 – 79% participation; and a weak rating is applied when the selected individuals are not likely to be representative of the target population or there is less than 60% participation or selection is not described. After scoring each criterion for a study, a global rating of strong is applied when no weak ratings have been found, a global rating of moderate is applied when one weak rating has been found, and a global rating of weak is applied when two or more weak ratings have been found. The studies were synthesized according to the intervention's target (e.g., improvement of mental health), social robot's main features applied for healthcare purposes (e.g., instructions and guidance), the robot used (e.g., Nao humanoid robot), study design (e.g., randomized controlled trial), number of enrolled participants, age of children or adolescents, participants' follow-up duration, primary outcome (e.g., anxiety) and whether this was found to be significantly positive. The systematic review was conducted following the PRISMA guidelines [14]. We have included a completed PRISMA checklist as Supplementary Material.

[1] https://www.ephpp.ca/quality-assessment-tool-for-quantitative-studies/

3. Results

3.1. Literature search outcomes

In total, 1229 records were obtained from Scopus and 88 records from PubMed (Fig. 1). The retrieved records were imported into the Mendeley© bibliography management software [15] and 46 duplicates were removed. The abstracts of the remaining 1271 articles were screened according to our inclusion and exclusion criteria, from which we identified 29 eligible articles. The reviewers read the full-text of those 29 manuscripts, and agreed to include 13 eligible manuscripts [16–28]. Reasons for the exclusion of the manuscripts can be found in Fig. 1.

3.2. Quality assessment

According to the EPHPP criteria, the methodological quality was found to be strong for 5 studies (38%) [16,18,19,22,23], moderate for 2 studies (20%) [24,26], and weak for 6 studies (46%) [17,20,21,25,27,28] (Table 1). The studies with weak rating were associated mostly with insufficient description on the validity and reliability of data collection methods, lack of description on withdrawals or dropouts of participants, and no dealing with confounding. In terms of study design, 6 studies (46%) [17,20,21,26–28] were of observational nature, and 7 studies (54%) [16,18,19,22–25] were randomized controlled trials.

3.3. Intervention target and main features

The 13 studies described social robot-based interventions which had different targets as follows (Table 2): a) 7 interventions (54%) [16,18,19,22–24,26] targeted the improvement of mental state of children, 4 of which [18,19,23,26] also examined the reduction of pain during needle insertion or vaccination, b) 2 interventions (15%) [25,27] targeted nutrition education, c) 2 interventions (15%) [21,28] targeted the improvement of playfulness and special education, d) 1 intervention (7%) [17] targeted exercise coaching, and e) 1 intervention (7%) [20] targeted childhood obesity prevention.

The Nao humanoid robot was used in 6 interventions (46%) [16,18,19,23,25,26], the IROMEC robot was used in 2 interventions (15%) [21,28], and a mobile robotic wheel base working with iPad [17], the Paro robot with the looks of a seal [22], the Huggable robot with the looks of a caring bear [24], the Dragonbot robot with a dragon appearance [27], and the Cozmo robot with the looks of a miniaturized bulldozer [20], were used in the remaining 5 interventions. Different robot features were utilized in the interventions. Guidance, explanation of concepts and provision of instructions were provided in 5 social robot-based interventions (38%) [16–18,23,25]. Reinforcement, reassurance and emotional support which were provided by the robot mainly through talks and sounds, were described in 6 interventions (46%) [16–18,20,22,23]. Games played between the child and the robot for education, entertainment, and distraction purposes were reported in 6 interventions (46%) [19,21,24,25,27,28]. All studies except the study by Crossman et al. [22], involved structured child-robot interactions based on specific scenarios, and the control of the robot by a researcher.

3.4. Participants, settings and outcomes

The average number of participants in the studies was 62 (range 3 – 190). The age of participants ranged between 2 and 17 years, but the majority of the studies targeted children in pre-school, grade-school or both. Participants were children with intellectual [21] (7%) or physical disabilities (7%) [28], children medically or surgically hospitalized (15%) [18,24], children with cancer or other chronic disease (23%) [16,19,23], children with no indication of a disease or disability (46%) [17,20,22,25–27]. The setting of the intervention was the hospital [16,18,19,24], school [20,25,27], community [17,22], pediatric care center

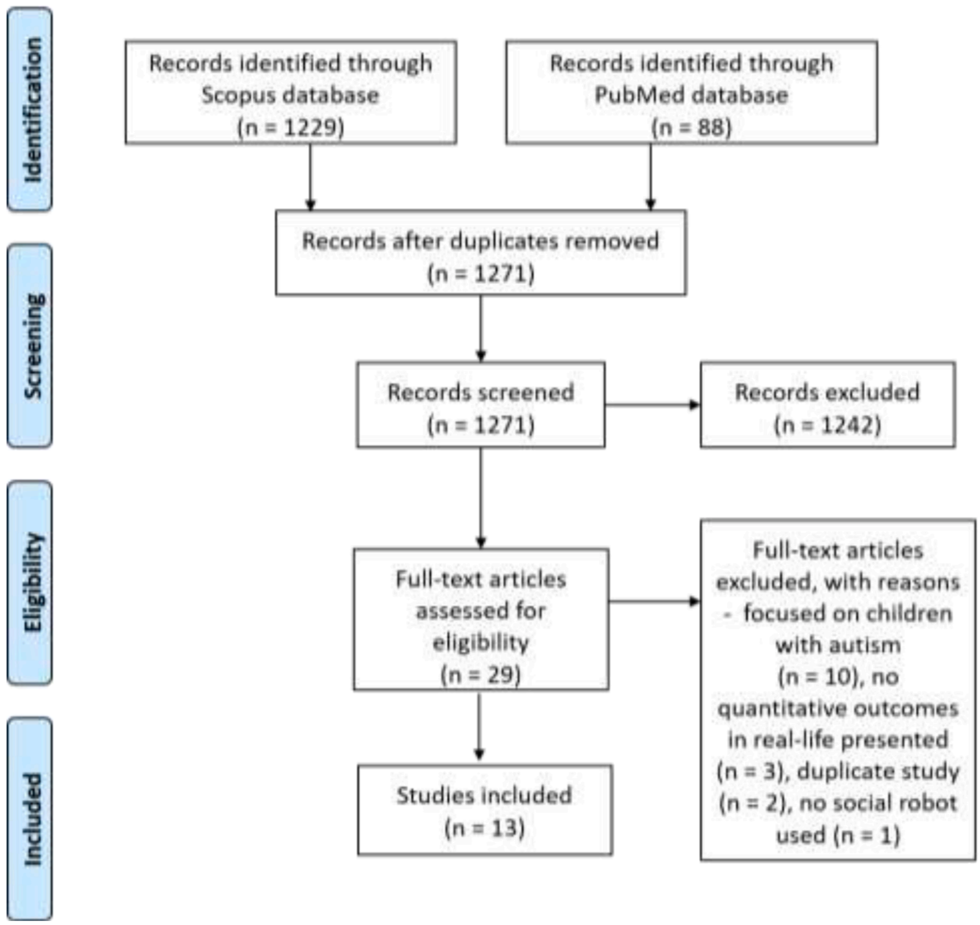

Fig. 1. PRISMA flow diagram for study inclusion.

Table 1
Quality assessment (W: Weak, M: Moderate, S: Strong) of included studies based on the EPHPP criteria.

Study	EPHPP criteria						Global rating
	Selection bias	Study design	Confounders	Blinding	Data collection	Withdrawals - dropouts	
Alemi et al. [16]	M	S	M	M	S	S	S
Ali et al. [18]	M	S	S	M	S	S	S
Barwise et al. [17]	M	W	S	M	M	W	W
Bernd et al. [21]	M	M	W	M	W	W	W
Crossman et al. [22]	M	S	S	S	S	S	S
Jibb et al. [23]	M	S	S	S	S	S	S
Logan et al. [24]	M	S	S	M	W	S	M
Rheel et al. [19]	M	S	S	S	S	S	S
Rosi et al. [25]	M	M	W	M	W	W	W
Rossi et al. [26]	M	M	M	M	W	S	M
Short et al. [27]	M	W	W	M	S	W	W
Triantafyllidis et al. [20]	M	W	W	M	S	S	W
Van Den Heuvel et al. [28]	M	W	W	M	W	W	W

[23], vaccination center [26], rehabilitation center [21], and one study was conducted both at school and rehabilitation center [28]. Interestingly, most studies (69%) [17–20,22–26] involved only a single session between the robot and the child, i.e., there was no follow-up. Other studies reported the conduction of 6 – 14 sessions. In all studies, the follow-up duration did not exceed 2 months.

The primary outcomes of the studies varied, and in total 11 studies (85%) [16,17,28,18–20,22–24,26,27] reported significantly positive outcomes of their intervention. In interventions targeting mental health, Alemi et al. [16] reported as outcomes anxiety, anger and depression in children with cancer. This was the only study having follow-up among the studies describing mental health interventions. Crossman et al. [22] reported on mood, anxiety and arousal. Jibb et al. [23], reported on the feasibility of the intervention as well as the pain, fear, and distress of children with cancer having needle insertions. Similarly, Ali et al. [18] examined distress as primary outcome in children undergoing intravenous insertion, and Rheel et al. [19] examined pain intensity in children undergoing a needle procedure. Logan et al. [24] had feasibility and acceptability, as well as positive/negative affect together with pain and anxiety as outcomes in hospitalized children. Finally, Rossi et al. [26] had pain and distress as primary outcomes in children having vaccination. Positive mental health outcomes were reported in all those studies, and interventions were deemed to be feasible and acceptable [23,24]. Details in the outcomes of the studies are illustrated in Table 3.

Table 2
Target and main features of the interventions in the included studies.

Study	Intervention target	Main features	Robot used
Alemi et al. [16]	Alleviation of distress in children with cancer	Instructions to children about symptoms and treatment, reassurance, provision of space for expression of fears/ worries and goals	Nao humanoid robot
Ali et al. [18]	Reduction of distress and pain in children undergoing intravenous insertion	Instructions for cognitive behavioral therapy-based strategies	Nao humanoid robot
Barwise et al. [17]	Exercise coaching	Reinforcement and support, demonstration of robot motion capabilities	Mobile robotic wheel base with iPad (Double Robotics Inc.)
Bernd et al. [21]	Improvement of playfulness in children with intellectual disabilities	Pre-defined play scenarios	IROMEC robot
Crossman et al. [22]	Improvement of mental health	Interactions with robot (pet, touch and talk)	Paro robot
Jibb et al. [23]	Reduce pain and distress in subcutaneous port needle insertions for children with cancer	Reinforcement, support, guidance, positive affirmation	Nao humanoid robot
Logan et al. [24]	Reduce pain and anxiety in hospitalized children	Interactions with robot (conversations about likes/dislikes, singing, playing a game)	Huggable
Rheel et al. [19]	Reduce pain in children undergoing a needle procedure	Quiz playing	Nao humanoid robot
Rosi et al. [25]	Improve nutritional knowledge	Explanation of concepts, game with children	Nao humanoid robot
Rossi et al. [26]	Reduce anxiety during vaccination	Provision of information, conversation for distraction	Nao humanoid robot
Short et al. [27]	Improve nutrition education	Small talks, food choice game	Dragonbot robot
Triantafyllidis et al. [20]	Prevent obesity	Screening and assessment of health behaviours	Cozmo robot
Van Den Heuvel et al. [28]	Achievement of therapeutic and education goals and improvement of playfulness in children with physical disabilities	Turn-taking game, control of robot by child, robot following children	IROMEC robot

In nutrition education interventions, Rosi et al. [25], and Short et al. [27], had as main endpoint the improvement of nutrition knowledge, however they did not detect any significant positive outcomes. Nevertheless, high enjoyment and engagement of children in the study by Short et al. [27] was demonstrated. Playfulness was the primary outcome in the studies by Bernd et al. [21] and Van Den Heuvel et al. [28], but no positive results were demonstrated apart from achievement of short therapeutic and special education goals in the latter study. Achievement of weekly health goals toward prevention of childhood obesity was the outcome of the study by Triantafyllidis et al. [20]. Technology acceptance was the outcome in the study for exercise coaching by Barwise et al. [17], yielding positive results.

3.5. Implications for clinical practice

Based on the outcomes of the social robot interventions, implications for the clinical practice can be outlined (Table 4). Most studies demonstrated that the efficacy of child health interventions can be improved if social robots assist with therapy [16,18,19,22–24,26,28]. In particular, the betterment of mental health of children during medical procedures or treatment, e.g., in terms of reducing anxiety and distress, has been found to be possible through the application of social robots. However, the therapeutic added value was found to be unclear in one study targeting children with intellectual disabilities [21]. Overall, social robots have been found to be engaging for children in therapy and health education, thereby promoting their collaboration with health providers and their adherence to treatment goals. Nevertheless, three studies indicated that the technology needs to be more stable and robust before its integration in the clinical practice [18,23,28].

4. Discussion

4.1. Main findings

This review systematically examined recent studies which applied social robot-based interventions for child healthcare. The main finding of the review is that social robots utilizing different features such as provision of instructions, reassurance and emotional support, as well as gaming capabilities, have been useful for children and their health providers.

Children could be benefited from the use of social robots in therapy, particularly for improving their mental health and alleviating conditions such as distress and anxiety, which may contribute to effective treatment and better well-being. In this context, further research in the application of social robots for child and adolescent mental health is warranted [29].

The recent COVID-19 outbreak forced children around the globe to be isolated at home due to quarantine policies, causing adverse psychological effects especially to those separated from their care providers [30]. In this light, social robots could be considered in the design of psychological intervention strategies, grounded on the mental health benefits demonstrated in this review.

However, methodological limitations have been found in most studies identified in this review, in line with previous examinations [3,9]. Particularly, the small number of participants in the studies along with their short timeframe and observational nature, do not permit to provide substantial evidence of the effectiveness of social robot interventions in child healthcare. Only 5 studies were found to be of strong quality according to the EPHPP criteria [16,18,19,22,23]. Interestingly, all those studies were concerned with mental health improvement and alleviation of distress in children.

The social robot interventions targeted alleviation of distress in children with cancer, exercise coaching, improvement of playfulness in children with intellectual disabilities, improvement of positive mood in therapeutic sessions, reduction of pain and distress in pediatric inpatient or outpatient settings, e.g., during needle insertions or vaccination, improvement of nutritional knowledge, and achievement of instant therapeutic or education goals in children with physical disabilities. The interventions were found overall to be feasible and acceptable by children and health providers in different settings such as hospitals, rehabilitation centers, pediatric care centers, and schools, thereby facilitating both primary and secondary care.

Social robots with talking, guiding, and gaming functions were engaging, which motivated children to become more interactive and collaborative. This reveals the potential of social robots in promoting healthy behaviours as well as adherence to therapy through their interaction capabilities. Considering that half of the included studies involved children with no indication of a disease or disability and described preventive interventions (e.g., through promotion of a balanced diet and regular exercise), more studies with children in

Table 3
A comparison of study design and structure of the research.

Study	Study design	Number of participants	Age	Follow-up duration	Primary outcome	Significantly positive outcome
Alemi et al. [16]	Randomized controlled trial	11	7–12	8 sessions (over 1 month)	Anxiety, anger, and depression level	Yes
Ali et al. [18]	Randomized controlled trial	86	6–11	No follow-up	Distress	Yes
Barwise et al. [17]	Observational study	190	12–17	No follow-up	Technology acceptance	Yes
Bernd et al. [21]	Observational study	3	3–5	12–14 sessions (over 6–7 weeks)	Playfulness	No
Crossman et al. [22]	Randomized controlled trial	87	6–9	No follow-up	Mood, anxiety, and arousal	Yes (positive mood)
Jibb et al. [23]	Randomized controlled trial	40	4–9	No follow-up	Feasibility, pain, fear, distress	Yes (feasibility and distress)
Logan et al. [24]	Randomized controlled trial	54	3–10	No follow-up	Feasibility and acceptability in pediatric care, positive and negative affect, pain and anxiety	Yes (feasibility, acceptability, and positive affect)
Rheel et al. [19]	Randomized controlled trial	22	8–12	No follow-up	Pain intensity	Yes
Rosi et al. [25]	Randomized controlled trial	112	8–10	No follow-up	Nutritional knowledge	No
Rossi et al. [26]	Observational study	139	3–12	No follow-up	Pain and distress	Yes
Short et al. [27]	Observational study	26	5–8	6 sessions (over 3 weeks)	Enjoyment and engagement, nutritional knowledge	Yes (enjoyment and engagement)
Triantafyllidis et al. [20]	Observational study	30	9–12	No follow-up	Achievement of recommended health goals	Yes
Van Den Heuvel et al. [28]	Observational study	11	2–8	6 sessions (over 2 months)	Achievement of education/therapeutic goals, playfulness	Yes (goal achievement)

Table 4
Implications for clinical practice.

Study	Implications for clinical practice
Alemi et al. [16]	Efficacy of child health interventions can be improved if social robot-assisted therapy is added, children can become more interactive and cooperative in their treatment
Ali et al. [18]	Social robot-based distraction is associated with positive impact on child distress for pediatric intravenous insertion
Barwise et al. [17]	Robotic-assisted exercise coaching is acceptable in adolescents
Bernd et al. [21]	The therapeutic added value of robotics interventions for children with intellectual disabilities is unclear
Crossman et al. [22]	Augmentation of positive mood in therapeutic sessions through social assistive robots, e.g., in children exposed to acutely stressful situations
Jibb et al. [23]	Social robots may mitigate pain and distress related to needle insertion – larger clinical trials are needed
Logan et al. [24]	Integration of social robots in inpatient pediatric settings is technically feasible, acceptable and beneficial for hospitalized children
Rheel et al. [19]	Robot-led distraction during needle procedures is feasible and it can reduce pain intensity in children
Rosi et al. [25]	Social robots don't improve nutrition knowledge in a school setting, longer trials are required
Rossi et al. [26]	Social robot distraction strategies provide relief to children in vaccination procedures
Short et al. [27]	Children can be engaged with social robots over time
Triantafyllidis et al. [20]	Social robot-based platforms to prevent childhood obesity have the potential to improve children's health behaviors
Van Den Heuvel et al. [28]	Social robots can help children with physical disabilities, but technical stability is required

specific conditions (e.g., cancer, diabetes, etc.) are needed. In this direction, computerized decision support systems for health providers aiming to harness knowledge regarding the health behavior patterns of children, and support them with treatment decisions, could be applied in interoperation with social robots [31,32]. The structured child-robot interactions in pre-defined scenarios as reported by the majority of the included studies, indicate that there is potential for new and original research in the unstructured operation of social robots in real-life settings, e.g. through machine learning approaches [33].

Interestingly, most studies had no follow-up and involved only one session between the robot and the child. In this regard, the studies have been remarkably limited and unable to detect any long-term effects of the social robot-based intervention. In the studies with follow-up, the number of sessions was very small (6–14) over a limited period of time (not exceeding 2 months), and they involved a small number of participants (3–26). On the contrary, there have been longitudinal interventional studies (up to 3–6 months) using social robots for older adults, e. g., for cardiac rehabilitation [34] or improving quality of life in elderly care [35]. Overall, these findings suggest that the research community should focus on the conduction of more rigorous research and longitudinal trials, in order to generate strong evidence of the effectiveness of social robot interventions in outcomes related to the health and well-being of children.

4.2. *Limitations*

The findings of this review should be interpreted considering its limitations. Although we used two well-established databases for the search of the literature (i.e., Scopus and PubMed), we acknowledge that certain studies might have been overlooked, due to the limited number of searched databases or because they did not meet our search word criteria. The grey-literature was not explored. Additionally, we have not been able to conduct a meta-analysis because the included studies were heterogeneous in their design and outcomes. The final sample of included studies according to our defined eligibility criteria has been limited ($n = 13$), which reduces the potential of generalizability of the review findings.

5. Conclusion

This review showed that social robots could be useful agents in the provision of healthcare services for children. Social robot engaging characteristics, e.g., in terms of appearance, talk and reactions, and gaming capabilities were found to be particularly helpful in improvement of the mental state of children, interactive guidance to promote compliance with medical procedures such as vaccination, as well as promotion of healthy behaviors such as exercise and balanced nutrition. Concerning future work, the review highlights the need to conduct rigorous studies and provide robust evidence of the effectiveness of social robots for child healthcare, e.g., in terms of improved self-management or prevention of health risks, in comparison with standard care.

CRediT authorship contribution statement

Andreas Triantafyllidis: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition. **Anastasios Alexiadis:** Data curation, Formal analysis, Writing – review & editing. **Konstantinos Votis:** Writing – review & editing. **Dimitrios Tzovaras:** Writing – review & editing.

Declaration of Competing Interest

The authors of this manuscript declare no conflicts of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cmpbup.2023.100108.

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