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The potential of robotics for the development and wellbeing of children with disabilities as we see it

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Abstract.
BACKGROUND: Rapid technological development has been opening new possibilities for children with disabilities. In particular, robots can enable and create new opportunities in therapy, rehabilitation, education, or leisure.
OBJECTIVE: The aim of this article is to share experiences, challenges and learned lessons by the authors, all of them with experience conducting research in the field of robotics for children with disabilities, and to propose future directions for research and development.
METHODS: The article is the result of several consensus meetings to establish future research priorities in this field.
RESULTS: Robots have a huge potential to support children with disabilities: they can play the role of a play buddy, of a mediator when interacting with other children or adults, they can promote social interaction, and transfer children from the role of a spectator of the surrounding world to the role of an active participant. To fulfill their potential, robots have to be "smart", stable and reliable, easy to use and program, and give the just-right amount of support adapted to the needs of the child. Interdisciplinary collaboration combined with user centered design is necessary to make robotic applications successful. Furthermore, real-life contexts to test and implement robotic interventions are essential to refine them according to real needs.
CONCLUSIONS: This article outlines a research agenda for the future of robotics in childcare and supports the establishment of R4C – Robots for Children, a network of experts aimed at sharing ideas, promoting innovative research, and developing good practices on the use of robots for children with disabilities.

Keywords: Children with disabilities, social robots, robotic assistive technologies, child development, child wellbeing

1. Introduction

Technology is rapidly developing and has revolutionized our world and daily lives, allowing us to stay socially connected despite the measures taken by many

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countries to fight the COVID-19 pandemic. Smartwatches, smartphones and fast mobile computers provide new opportunities in private and professional life, but also in healthcare. Robots, i.e. "actuated mechanism[s] programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks" [1], are among these new technologies. There are many different robots and a not exhaustive classification can be found in [2]. Service robots are those that perform "useful tasks for humans or equipment excluding industrial automation applications" [1]. Professional service robots are considered as an interesting mean for example in hospitals to support treatment [3]; personal service robots have supported children with disabilities in play [4], academic activities [5], or therapy [6–8]. Social robots are a relatively new technology being increasingly developed, tested, and used in healthcare contexts [9–11]. Socially assistive robots (SAR) are designed to interact with humans in a social way and often come in the shape similar to a pet or human [12]. Due to their ability to engage people through social and emotional dimensions, SARs are deemed as particularly suitable in healthcare contexts to help people achieve personal goals, for instance by motivating, coaching, or enabling communication [9,10].

Robots are being applied for different target groups, e.g., elderly people with dementia, older people living individually, children with Autism Spectrum Disorder (ASD), or children with cerebral palsy [13–17]. Research on robotics for children with disabilities, in particular, has taken in the last decade an important place in the field of innovative technologies. Illness or disabilities can isolate children from their regular social network or can hinder communication and interaction, their development and their involvement in daily life situations. Parents and professionals have been seeking toys and tools, among these also robots, to support children optimally. Robots for children with disabilities are a promising field for several reasons. First of all, children in general are attracted by robots, especially children with ASD [18,19]. This positive attitude towards robots is also mirrored by children and parents in pediatric rehabilitation [17,18]. Furthermore, robots have a physical presence and can act upon the environment compared to e.g., graphical avatars [21]. What makes robots also interesting is programmability and autonomy, which makes them adaptable to the needs of a child which is particularly important for tailored interventions [22].

Despite their showing great promise, concerns however remain regarding the potential of robots in applied settings, as they are not yet considered usable outside of controlled environments or isolated structured interactions. As a consequence, professionals' interest in adopting potentially useful robotic applications is challenged by the difficulties they face in integrating such innovative platforms within their everyday clinical or educational practices.

In light of these considerations, this opinion article is aimed at sharing experiences, challenges and learned lessons mentioned by researchers working on the application of robots for children with disabilities or children in a hospital, and at proposing future directions for research and development with a view to improve transferability of robotics applications in a variety of applied settings. Several meetings were held and conclusions of those meetings were shared with a larger network for further elaboration and feedback, to formulate a joint vision for this field. By means of this opinion article, we aim at establishing the R4C – Robots for Children – network, connecting people (researchers, practitioners, designers, etc.) interested in the general theme of robotic applications for children.[1]

2. Benefits of robotics for children

Over the last decade (i.e., 2010–2020), 18 systematic reviews have examined the potential of robots for children in rehabilitation, (special) education or hospital settings in improving daily activities, learning, and development. Most research with social robots seemed to be carried out with children with ASD to support communication and interaction, joint attention, learning and eliciting behaviors, and skills' performance [14,18,22–25]. Specifically, robots have been used with children with physical impairments as assistive technologies to support play (especially play for the sake of play), learning, upper arm function and enabling participation in occupations requiring manipulation of objects [25–28]. Children with a chronic illness or undergoing medical and/or mental care received benefits from a social robot as it can be a companion to support stress and pain reduction, to help manage the disease and treatment, and to communicate with family and professionals [29–33]. Different reviews mentioned the positive effects of a humanoid robot as a tool in learning e.g., for teaching and instruction and for peer support in order to elicit behaviors and to improve cognitive,

[1] For more information about the R4C network, please visit the website: https://sites.google.com/view/robots4children/home.

language and social skills [24–26,34–37]. In an EU-funded project, DREAM, the next generation robot-enhanced therapy was envisioned. Different areas were studied, e.g., clinically relevant interactive capacities for social robots that could operate autonomously, policy guidelines and a cognitive model that interprets sensory data to assess the child's behavior. Robots NAO and Probo were used during this project [38]. In the context of the measures to prevent the spread of COVID-19, research has also focused on the use of social robots in supporting children with ASD receiving communication education while maintaining social distancing (e.g., [39]).

In sum, using the language of the International Classification of Functioning, Disability and Health for Child and Youth [40],[2] a number of studies showed that robots for children can support improvement of body functions, activity performance and participation, as well as being a supportive environmental factor.

3. Current challenges

The majority of the aforementioned studies described an improvement in the performance or abilities related to medical, wellbeing, educational or rehabilitation objectives, in pupils' engagement and interaction with peers. However, all the reviews mentioned concerns about the explorative nature of the reported studies and the methodological limitations. All authors emphasized the potential of robots for children and recommended to continue research in this area, however with larger sample studies, with more rigorous methodologies, with carefully diagnosed groups of participants, listening to parents and teachers.

It is clear from the different reviews and European projects that several types of robots deployed as professional support for children with disabilities are still under development [30]. Although the technological status of robots is promising, the literature reviews stressed the need for further technical developments e.g., improving speech understanding in real settings, possibly reproducing human-like behavior, enabling double initiative interaction (robot can elicit behavior of the child and can respond to the child's initiatives). In summary, the robot should enable adaptive interventions tailored to the specific users and possibly exhibit some degree of autonomous behavior [22,30,34]. For actual implementation, commercial availability of the different technologies also plays a crucial role, which implies reliability and accessibility of the technologies [27,30].

According to different authors, a critical aspect to consider is the integration of the robot intervention in the educational or therapeutic programs. This requires understanding of and connecting to the theories backing up these programs [34]. The clinician (or any other relevant caregiver) should have a prominent role in (a) deploying the robot, (b) developing scenarios for the robot which engages the child, (c) applying the robot as a tool to achieve child(ren)-centered goals, and (d) evaluating the outcomes [20,24,25,29,31,32,36]. Ideally, the robot and the encompassing software should be easy to use and should provide opportunities to the adult for personalized evidence-based interventions supporting the child's daily life activities [18]. The involvement of adults in a user-centered design approach appears to be a key factor for success [14,18,23,25,26,34,36]. The influence of context seems to be important as well. The choice of the robot and the context of deployment is related to the intended child-robot interaction in which the functionalities of the robot play a relevant role [22,30,33]. Different researchers plead for more emphasis on how the learned skills with a robot intervention can be transferred into contact or activities with humans [22–24,30].

None of the authors in the systematic reviews described the characteristics of a target group which might benefit from robotic intervention the most. There is a lot of variety within the target groups regarding both age and health conditions. The main common characteristic of the target groups is including children that needed intensive ongoing care. The variety of robots is even larger, and some robots are still in a developmental phase, with experimental features. Dawe and colleagues [30] mentioned 26 different robots deployed in different studies. They recommend, together with other authors, joint future technological developments with a user-centered design approach [25,30].

4. Our learnings to make robots effective

Over the last ten years, the authors of this paper participated in various research projects involving the use of (social) robots in educational as well as clinical set-

[2]The definition of disability of the World Health Organization is adopted in this article, in which three dimensions are highlighted: impairment, activity limitation, and participation restrictions. The concept captures all kind of needs as well as illness. World Health Organization, (2011). World report on disability. Chapter 1: Understanding disability. Retrieved from https://www.who.int/publications/i/item/world-report-on-disability.

Table 1
Overview of the five dimensions for effective robot use, namely robot roles (Robot), target groups (Children), requirements for their use (Professionals), settings of use (Environment), and objectives of use (Aim)

Robot	Children	Professionals	Environment	Aims
– Buddy/mediator/social interactor/assistive tool – “Smart” – Technologically stable – Reliable – Low cost – Easy to program – Just-right amount of support – Appealing to children	– Autism spectrum disorder – Neuro Developmental Disorders in general – Hospitalized children – Physical impairments	– Able to operate the robot easily and quickly – Able to program robot themselves – Interdisciplinary collaboration needed	– Real life contexts (e.g., school, home, care center, hospital, kindergarten)	– Functioning independently – Having a buddy which supports playing, learning and other daily activities – Engage children in more complex and natural relationships in a non-structured context – Stimulate children to stay on task, quickly capturing children’s attention and facilitate perceptual processes – To motivate learning – Involve children with disabilities in play – Enable participation in occupations requiring the manipulation of objects – Collect data

tings. Based on this experience, we identified five dimensions of robot use (Robot, Children, Professionals, Environment, and Aim) that need to be considered to make robot-based intervention effective. In Table 1 we provide an overview of these five dimensions for effective robot use, which are explained in detail in this section.

Available research has clearly shown the potential and the need for a buddy/mediator/social interaction robot with which children can interact and which can be controlled independently. The adult (therapist, teacher, parent, etc.) can play an intermediate role by preparing the scenarios of the robot and by stimulating child-robot interaction. On other occasions, the robot could take the role of facilitator of the interaction between the child and either the adult or the child’s peers. Available research has mainly focused on buddy/social mediator robots for children with ASD and hospitalized children. Research data show the benefits of children using a robot in their daily context e.g., stimulating interaction and communication for children with ASD, reducing the stress level of hospitalized children, motivating children to participate in therapeutic activities. Social robots can also be beneficial for children who experience activity limitations or participation restrictions due to other impairments in one or more domains of functioning, such as cognition, communication, mobility, or learning. Applications examples are engaging children in more complex and natural relationships in a non-structured context, stimulating children to stay on task, capturing quickly children’s attention, motivating and facilitating learning or involving children in play.

Robots may also be useful as augmented manipulation assistive technologies, as a means for children with physical impairments to act upon the environment. The robotic augmented manipulation assistive technologies may be programmed to adapt to the children needs, providing the just-right amount of support and allowing the children to take control of the activity up to the level of their abilities. This is particularly relevant in play and educational activities where children should be able to explore these by themselves and be in control of the activity.

Robots can promote the development of more inclusive practices, thus offering opportunities to children with disabilities to interact with their peers and significant others, for example by making play or academic activities accessible for all. As such, robots are tools to foster the integration of people with disabilities. A precondition is that enough time is needed for the child to be able to complete the robot mediated activities, especially along with peers. The availability of inclusive and accessible environments as well as the design of personalized learning activities are also instrumental to achieve the desired outcomes.

Robots for these applications have to be “smart” (e.g., functioning (semi-)autonomously), technologically stable and reliable. Cost of robots should decrease to hundreds of Euros instead of thousands to move from a niche market for specialized experts to instruments of current practice. Since robots can be used for a number of different activities, they can be cost-effective tools if cost decreases to these values. The robots should be easy to use and program by non-technical persons, allowing any adult to operate the robot and define intervention scenarios by him/herself.

It is worth noticing that even inexpensive robots (costing less than 100 Euros) can be successfully used as play companions, when integrated in well-designed activities, and when they were conceived considering the final users' needs and preferences.

Adults and practitioners may also benefit from the adoption of a robot. Robots augment the possibilities for the therapist/teacher to provide personalized support. Significant others as parents may feel somewhat more motivated to take part in innovative practices and may create new educational and therapeutic scenarios. Robots are exceptional tools to collect objective information about the progress of the children (e.g., cognitive development, rehabilitation goals), which can support better tailoring of future support. We recognize that using robots outside controlled environments may be a difficult and expensive task; however, only in the real-life context it can become clear what the benefits are for involved children and adults regarding participation and wellbeing. An interdisciplinary, cross-sectoral collaboration, including academics, robotic companies, children, parents, teachers, therapists, pedagogists, software and hardware engineers, technicians, should be involved from the beginning of the development of robots and interventions. The end-user should always be at the center of the process and have the final word in all strategic decisions, embracing a user-centered co-design. No technology will be worth developing if it ends up not being used because it does not answer to the end-user needs. Cooperation between parents and professionals supporting children (so called users), and technology experts (so called makers) is crucial for success.

5. Our vision and research agenda

We envision a world in which robotic applications are available and accessible for all that may benefit from them, in particular vulnerable children. In that world, robots are part of the daily activities of the children in different settings. Robots are technologically stable and reliable tools easy to control and to program by non-technical persons (e.g., therapists, teachers, nurses, parents, etc.) upon little training and with technical support upon request. Robots are interactive and able to respond to and adapt to the children's needs. Children are in control up to the maximum of their abilities, when a robot takes over to perform what the child is

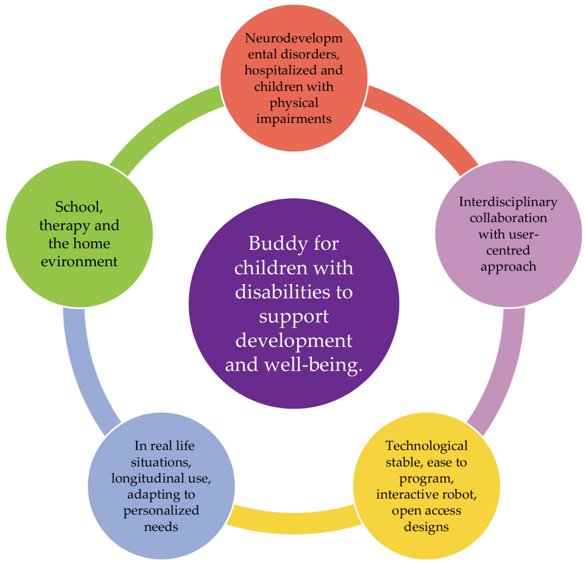

Fig. 1. Visual representation of future vision.

not (yet) able to do. Trans-disciplinary teams ensure the success of user-centered robotic applications and that skills gained in robotic interventions carry over to different physical and social environments. Figure 1 illustrates this vision.

We believe that, to achieve that goal, a trans-disciplinary perspective of robotic applications is necessary. User-centered co-design methods should be followed. Therapists, teachers, parents, etc. should have a central role in developing scenarios where robots may be useful tools to achieve child(ren)-centered goals, in deploying robots, and in evaluating the outcomes. Robots' development should be an iterative process, with different versions being integrated in real-life settings, being part of children's daily activities, collecting data and being upgraded based on meaningful data. That implies a culture of cooperation between developers and end-users, allowing for pilot testing of the robots, for extensive periods if necessary, assessing aspects of the actual use of the robot that cannot be determined in detail beforehand such as feasibility or integration in daily routines, to achieve a final product that actually meets the needs of the end-users. Robot designs (software and hardware), application scenarios, collected data, etc. should be made accessible to all fostering wide adoption of robotic solutions, for example in health care and education.

To realize our vision, the R4C network will strive to promote applied and basic research in the fields of robotics and assistive technology to address some of the main challenges faced by professionals and researchers in the implementation of these solutions in daily contexts. In this view, our research agenda includes six areas of intervention.

Area 1: Evidence-based practice and transferability. This paper is grounded on the (evidence-based) idea that robots may benefit children with disabilities by promoting their, physical, cognitive and social development, as well as their health and quality of life. Overall, it can be argued that the amount of available evidence is rapidly increasing. More importantly, the most recent literature clearly shows that research in this field is moving from anecdotal or small-scale studies to larger and reliable clinical investigations aimed at demonstrating what types of robots may be useful, for whom, and in what conditions (see e.g. [41]). It should be noted, however, that evidence collected so far may be applicable to the specific contexts in which it has been gathered, leaving the question open concerning the transferability of robot-based intervention protocols from one context to another. Accordingly, to strengthen the available evidence and help the field make a step further towards the understanding of whether robots can be considered useful assistive solutions for children, their parents, and professionals, we propose that (1) research/intervention protocols should be developed considering cross-country variabilities (e.g., cultural, policies) [42], and (2) tested according to an internationally agreed framework for reporting the outcomes of such research/interventions.

Area 2: Sharing experiences: Evidence suggests that robots may be useful in applied settings (e.g., clinics, hospitals, schools), but their implementation in daily practice may be hindered by several context-specific organizational, technical, financial, and personal barriers. What are the available good practice examples of robot implementation and what are the best strategies to help professionals implementing a robot in their daily activities and cope with the cost associated to acquire, maintain, and operate a robotic agent? To answer these questions, here we argue, it might be useful to develop an open online repository where researchers and professionals can present their experiences in a common format, so that it would be easier for professionals to understand the various applications of robotics, compare the different robot uses, and identify promising approaches.

Area 3: Technology developments and requirements: The enthusiasm about the potential benefits of robots is threatened by the limited capabilities of commercially available (and more advanced) robots to autonomously engage people in reliable, long-lasting, and flexible social interactions [43]. New developments in artificial intelligence and machine learning would certainly help robots acquiring better cognitive and social skills, but the time needed to reach these technical achievements – as well as to make the clinicians and other caregivers comfortable with these technical features – may lead to a widespread disinterest towards the implementation of these solutions in applied settings [44]. Research can be focused on identifying the minimal 'cognitive' requirements for a robot to be perceived as flexible enough to engage children with various disabilities in meaningful, long-lasting, and socially rich interactions.

Area 4: Relationships and acceptability: Long-lasting interactions with (social) robots are determined by the extent to which the child – as well as the adults – accept them in their life contexts [45]. Technology acceptance, in general, is a complex construct that may vary according to the type of technology, context of use and target users. Lack of perceived usefulness due to technical issues or difficulties in operating a robot, for instance, may lead to low acceptance despite evidence of its effectiveness in a particular context. Research can be promoted to understand what are the specific factors that determine robot acceptance in a variety of settings (e.g., clinics, hospitals, schools, homes) and for a variety of user groups (e.g., ASD, intellectual disabilities, physical impairments, hospitalized children).

Area 5: Ethics: Evidence shows that all children may form social bonds with robots [46]. While many scholars acknowledge the potential benefits for children of engaging in social interactions with robots, others highlight the potentially negative consequences for children's psychological and social development [47]. For instance, it has been suggested that regular interactions with artificial social agents may lead certain individuals to become less prone to engage in real social interactions [48]. Despite evidence of their usefulness, the use of robots that are capable of engaging children in social interactions by forming attachment or creating expectations, may pose ethical challenges that become especially important in childcare [48]. For this reason, it is important to (1) understand what are the main issues that may occur when children form emotional relationships with robots and (2) how professionals – as well as parents – may create the conditions to prevent such issues/risks. Ethical guidelines may be needed to create a common framework to promote safe and effective use of robot applications in different contexts.

Area 6: Professional development: Once reliable, easy-to-use, and cost-effective robots are available, evidence-based protocols for their use are developed, and application scenarios are shared, training packages for rehabilitation professionals and parents need to be devised.

6. Conclusions

The technological possibilities in robotics are enormous. It is up to researchers, parents and practitioners to collaborate, to share existing expertise, and to continue collecting evidence on real-life robotic support for children's development and wellbeing. The ultimate goal of research should be working with and for children with disabilities to contribute to their optimal participation in the society surrounded by significant adults and peers, capitalizing on the potential of robots to promote more innovative and inclusive life environments. Having a network with a relatively large number of members may help to overcome the difficulty in running studies with a significant number of participants. Furthermore, the size of the network may also help to bring the costs down (economies of scale) and having an international network is key to develop "culturally sensitive" robotic applications, since we know that educational or therapeutic systems differ from country to country. With this article the authors invite readers who recognize themselves in our vision to join R4C – Robotics for Children, a research and development network aiming at the advancement of robotic applications for children.

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Ethical considerations

Not pertinent.

Conflict of interest

The authors declare no conflict of interest.

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