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Robot-mediated pediatric neurorehabilitation

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Abstract

The huge complexity and variety of deficits in children, their continuous development, and co-operation simultaneously with children and their parents make clinical practice in pediatric neurorehabilitation particularly challenging. Thus scientists and clinicians still look for newer, more efficient diagnostic and therapeutic tools. One of them is robot-mediated pediatric neurorehabilitation. However, the amount of research in the area of robot-mediated pediatric neurorehabilitation is still limited, and its impact on clinical practice seems to be underscored. The aim of this study was threefold: to establish the current state of robot-mediated pediatric neurorehabilitation, investigate the extent to which the available opportunities in robot-mediated pediatric neurorehabilitation are being exploited, and discuss clinical perspectives and directions for further research.

Introduction

The huge complexity and variety of deficits in children, their continuous development, and co-operation simultaneously with children and their parents make clinical practice in pediatric neurorehabilitation particularly challenging. Thus scientists and clinicians still look for newer, more efficient diagnostic and therapeutic tools.

The continuous development of robotics and control systems provided socially intelligent robots that can collaborate/interact with people with an aim to fulfill some activities together [1]. The introduction of robots to rehabilitation may provide a significant impact on clinical practice, but also provide another breakthrough in more than one area of rehabilitation. In the opinion of many researchers and according to the experience of clinicians, robots may be useful as novel therapy tools, both basic or supplementary. Robots may improve the effectiveness of the diagnostics and/or therapy (e.g. rehabilitation robots used in gait re-education or robot-mediated upper limb physiotherapy), assess the response of patients to robots/behaviour, increase patient’s engagement and motivation (e.g. therapy as a game in children), model, teach, and/or practice skills, provide feedback on their performance (e.g. in home-based telerehabilitation), and elicit novel social behaviors from patients [2]. These issues are particularly important in children and teenagers.

Some introduction to pediatric therapeutic robotics was provided in our earlier paper [3]. However, the amount of research in the area of robot-mediated pediatric neurorehabilitation is still limited, and its impact on clinical practice seems to be underscored. The aim of this study was threefold: to establish the current state of robot-mediated pediatric neurorehabilitation, investigate the extent to which the available opportunities in robot-mediated pediatric neurorehabilitation are being exploited, and discuss clinical perspectives and directions for further research.

Robot-mediated physiotherapy

Robot-mediated physiotherapy may provide function recovery in an enriched environment. Enhanced feedback, personalization, and task relevance can be provided by:

- more accurate diagnosis and continuous outcomes analysis (where available),
- increased engaging environment: better motivation thanks to video games or virtual reality (VR), challenging purposeful tasks, customization/personalization, continuous learning, involving task-oriented exercises and increasing task complexity,
- features of automatic/mechatronic devices: increased quantity and quality, decreased errors, learning promotion,
- improved use of central nervous system (CNS) plasticity, thanks to motor learning design and control strategy,
- improved carryover of skills to the real world: tasks oriented to the particular activities of daily living (ADLs), and decreased learned nonuse [4].

Complex problem solving (faster motor learning, more natural movements, real activities, feedback and task engagement) needs incorporation of the aforementioned rules within diagnostic/therapeutic systems combining custom-shaped games, low-cost robotic systems, and novel control systems based on artificial intelligence. An additional issue is data presentation for purposes of continuous robot supervision by the therapist, therapy adjustment, and various alerts.

Many rehabilitation robots have versions dedicated to children, but they are usually only adapted versions of robots for adults (e.g. Lokomat). However, children need dedicated solutions [5, 6, 7]. Moreover, children with neurological gait disorder may modify their activity according the scenario, but its extent is determined by cognitive functions and motor impairment [5].

Austism spectrum disorders and other cognitive diseases

At least several studies showed evidence of the effective social human-robot interaction in children with autism spectrum disorders (ASD). This group of children is regarded as affected with a disability to communicate and to understand social cues. In recent research by Kim et al. [8] concerning social behaviors of 4- to 12-year-old children with ASD, these children spoke as much to the the adult interaction partner as to the robot, while partner varied randomly. Previous research by Costa et al. [9, 10] concerned positive outcomes of the use of LEGO Mindstorms robots to the therapy for autistic adolescents. The therapy took the form of robot-mediated play/interaction with four scenarios. Thanks to it promoting functional abilities (motor coordination and accuracy) and cognitive skills (social interaction, communication, attention, and collaboration), it was successful. Research with visuomotor priming by Peirno et al. [11] showed that children with ASD may try to understand a robot’s action and to imitate this action. This way they could achieve a core component of human social behaviour: imitation skills, particularly reach-to-grasp movement. This required only simple stimuli with an incomplete robot: researchers used only a robotic arm. Simple imitation was used also in the research of Billard et al. [12] where a simple doll-shaped imitator robot named Robota was used both to assess children's imitation ability and to teach them simple coordinated behaviors.

A review by Scassellati et al. [2] showed an entire family of socially assistive robots (SARs). These robots are used to assist patients with special needs (through social interactions). But such interaction, for the purposes of increased effectivity, should be individually tailored to the particular patient's needs, goals, condition, and even mood [13, 14, 15]. This may influence the control system of such robots – interaction should be shaped by:

- the clinical environment (including the current health status of the patient, etc.),
- general scenarios of interaction (usually common for robots),
- where available: previous experiences (robots learn and remember how to interact with a particular user, e.g. inputs regarded as more attractive are reapeated more frequently),
- the invention of robots based on current interactions with children,
- the therapist controlling the robot and updating its program, if necessary.

A similar solution was described by Gillesen et al. [14]: NAO robot accompanied by visual programming environment TiViPE. This environment used simple scenarios with blocks-like learning objectives put on an intact original scenario.

Therapeutic abilities may also be increased in mobile robots. Mobility (intentional and purposeful motion) gives to a robot an increased ability to interact with a child/children, obtain their attention, and engage them. It may be very useful in robot-assisted diagnosis, and further learning [16].

The concept of a robotic toy/companion being useful in pediatric neurorehabilitation becomes a reality. An individual approach to the patient needs new robotic abilities: relative quickness in learning new tasks, skills and individual preferences of the children. Research on such robots are conduced in Japan (PARO, Keepon, Aibo, Actroid), USA (RoboPAnd, Cog, Kismet), Korea (Kobie, Rabie, Pomi). But there is need for additional research concerning the most attractive robot/companion for children with various kinds and levels of deficits.

Assessment of healthy children

The aforementioned methods, tools, and techniques may be used to assess the development of healthy children. Novel technologies, such as eye-tracing (also used before in ASD children [17, 18]), brain computer interfaces, systems of three dimensional movement analysis (including gait analysis, and upper limb movements analysis), and many other sensors (e.g. breathing sensor) allow for quite novel approaches in the assessment of children, and the early detection of possible changes (screening) [19, 20, 21, 22, 23]. Such solutions force changes in the diagnosis, therapy and care in newborn infants, babies and small children, thus causing more breakthroughs. Such systems built into the child environment (toys, cradle, etc.) may constitute another component of pediatric early detection systems, increasing the safety of babies. This is the aim of scientists conducting research within NCN project “NeuroPerCog: development of phonematic hearing and working memory in infants and children” (head: prof. Włodzisław Duch).

Discussion

The limitations of the wider clinical application of the robot-mediated pediatric neurorehabilitation are the following:

- very little research supporting the usefulness of robots in the neurorehabilitation of children, especially randomized controlled trials (RCTs) fulfilling evidence based medicine (EBM) requirements,
- the unknown long-term influence of social interaction with robots to a young developing organism,
- the education of medical staff, and the incorporation of many novel specialists (including engineers) into everyday clinical practice,

- many ethical issues, e.g. the concept of a “social relationship” between robot and human,
- many legal issues, e.g. the decisions concerning the shape of the interactions (e.g. predefined scenarios) and the shared responsibility for the safety of the young patient,
- tasks concerning analyzing robot decisions, human-robot interaction, and systems' evaluation may be hard to fulfill in the case of the most advanced robots with built-in artificial intelligence,
- a lack of technical standards and clinical guidelines,
- the unknown validity and reliability of this technique.

Directions for further research in the area of social robotics are as follows:

- the requirements of social skills for robots (including social rules for robot behaviour that are acceptable for humans), and entire human-robot interaction [24],
- how current and future research can shape the rehabilitation of children with complex developmental disabilities,
- collaboration between robots, therapists, and engineers,
- factors influencing human-child interaction: age, gender, kind and severity of disorder, used therapeutic methods (NDT-Bobath, Vojta, others) and pharmacotherapy, shape (color, facture, etc.) and abilities of the robot, strength of the robot-child relationship, scenarios and other features of the robot program (e.g. number of parameters shaped by the therapist),
- possibilities of the use of outcomes in other applications, e.g. in geriatric therapeutic robots, or wider ranges of activities (increased independence of disabled people),
- the therapeutic use of the socially interactive robots in ambient intelligence (AmI) and affective computing (AC) environments,
- risk analysis, threats identification, including dehumanization of the health care and even whole human development.

Among the key challenges identified with social robotics are the technology's newness, especially in the area of expressive natural interpersonal interaction [1].

Conclusions

Considering the challenges and future trends in this rapidly developing research area, a more holistic approach to children can be provided according to the biopsychosocial model of health care and social care. Current possibilities are not fully applied, and there is need both for more scientific and clinical research, and education of multidisciplinary therapeutic teams. Key components should be risk analysis, and threats identification.

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