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A perspective on intelligent devices and environments in medical rehabilitation☆

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Abstract

Globally, the number of people older than 65 years is anticipated to double between 1997 and 2025, while at the same time the number of people with disabilities is growing at a similar rate, which makes technical advances and social policies critical to attain, prolong, and preserve quality of life. Recent advancements in technology, including computation, robotics, machine learning, communication, and miniaturization of sensors have been used primarily in manufacturing, military, space exploration, and entertainment. However, few efforts have been made to utilize these technologies to enhance the quality of life of people with disabilities. This article offers a perspective of future development in seven emerging areas: translation of research into clinical practice, pervasive assistive technology, cognitive assistive technologies, rehabilitation monitoring and coaching technologies, robotic assisted therapy, and personal mobility and manipulation technology.
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1. Introduction

There is a large and growing segment of our world population—people with reduced functional capabilities due to aging or disability. The number and percentages of people in need of advanced assistive technology are increasing every year. About 60 million Americans have a disability that affects one or more of their major life activities [1]. Perceptive, cognitive, and musculoskeletal diseases that impair motor skills dramatically increase with age. A number of subpopulations are of particular interest. In 2030, over 20% of the U.S. population will be over 65 years of age, with one in two working adults serving as informal caregivers [1]. Globally, the number of people older than 65 years is anticipated to double between 1997 and 2025. There is little debate that the 76 million American children born between 1945 and 1964 represent a cohort that is significant on account of its size [1]. Boomers account for about 39% of Americans over the age of 18 and 29% of the total population [1]. Adults with disabilities comprise approximately 21,455,000 of the 169,765,000 of working-age individuals in the US. However, only 30% of adults with disabilities are employed [2]. In Japan, the percentage of people of the age of 65 is also on the rise and it is project that by 2030 that approximately 30% of the population will be over 65 [3]. In Europe it is projected that by 2060 that 30% of the population will be over 65 [4]. As individuals, families, communities, and a planet, we are facing

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new technical and social challenges to attain, prolong, and preserve quality of life.

Recent advancements of technologies, including computation, robotics, machine learning, communication, and miniaturization of sensors bring us closer to futuristic visions of compassionate intelligent devices and technology-embedded environments. While many intelligent systems have been developed, most of them are for manufacturing, military, space exploration, and entertainment. Their use for improving health-related quality of life has been treated as a specialized and minor area. Assistive technology, for example, has fallen in the cracks between medical and intelligent-system technologies. The missing element is a basic understanding of how to relate human functions (physiological, physical, and cognitive) to the design of intelligent devices and systems that aid and interact with people.

The purpose of this manuscript is to highlight some of the emerging research topics in medical rehabilitation that should be possible because of advances in technology. It is not intended as an exhaustive review of assistive technology, but rather to provide a perspective into some of the requirements, challenges, and possibilities of future assistive technology.

2. Translation of research into clinical practice

Rehabilitation engineering research is generally conducted within the scope of health professions, basic science, and engineering programs [5]. Rehabilitation engineers (RE) may define their occupational roles as primarily involving clinical care and service delivery, design and development, or research, or may be involved in a combination of these activities [6]. The field of rehabilitation engineering integrates clinical care and research, allowing each to influence the future direction of the other.

Obtaining reimbursement for advanced medical equipment and technology can be challenging, especially if there is insufficient scientific evidence to justify the utility, efficacy, durability, or impact on function that a device has. Research can fill the gaps in scientific knowledge that aids consumers and clinicians in selection of appropriate devices and treatments and lends credence to why they may be a necessary part of medical care. For instance, insurance policies on reimbursement for power seat functions for power wheelchairs often have little or no basis in the scientific literature [7]. To this end, research that adds to the scientific knowledge in this domain aids not only clinical decision-making but also justification of those choices. For example, the effects of power features such as tilt-in-space and recline on seating interface pressures have been a major topic of interest [8–11].

Alternatively, rehabilitation engineering research fuels the development of evidence-based practice. The aforementioned studies on power seat functions have contributed significantly to the development of a clinical position paper from Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) [12]. Likewise, well-designed biomechanics studies on manual wheelchair users have elucidated the biomechanical forces, transfer techniques, and propulsion patterns that are significant sources of upper limb pain, injury, and disability; these studies have helped to formulate clinical practice guidelines that are now standards of medical care in spinal cord injury [13].

Technology transfer is the process of developing practical applications for the results of scientific research. Funding for research and development may be the largest and most significant obstacle. Often, partnerships between academic institutions and industry partners are then necessary to bring technology to the market. Scientific information must be published and disseminated. Finally, consumers and clinicians must have access to this information and be able to incorporate it into their lives and clinical practice [5].

3. Pervasive assistive technology

A dilemma faced by clinicians is reconciling the fact that observations of patients only occur during infrequent, face-to-face meetings in a clinic or laboratory, while ideal observations are assessments that reflect the patient's capabilities in the real world, where distractions are present and multi-task performance is often required. As such, there is a need for *ecologically valid* tests that provide information about a person's ability to function in a real-life environment [14]. One way to obtain ecologically valid measures is through the use of ubiquitous computing. Sensors integrated into the patient's environment as part of a "smart home" can allow healthcare professionals to obtain a much clearer view of the patient's condition than is available from short periods of monitoring in a clinical setting [15].

"Pervasive healthcare technology" offers the potential for continuous measurement, processing and communication of physiological and physical parameters from patients to service providers, family and other support people [16–20]. Technological advances in application-specific integrated circuits (ASICs), battery capacity and wireless technology have resulted in reduced size of medical sensors and systems, the ability to communicate wirelessly, and the ability to operate on batteries for prolonged periods of time [15,21]. Devices can therefore be integrated into the patient's environment, or even the patient's clothing, allowing healthcare providers to obtain a much clearer view of the patient's condition than is available from short periods of monitoring in the hospital or doctor's office [15] The appropriate design and integration of different kinds of sensors, as well as the appropriate medical algorithms to process the data could offer new possibilities for preventing health risks [15,18,22], managing chronic diseases [16,18,19,23–27], and providing support to elders and people with disabilities living independently [16,19,22,26,28,29].

Pervasive healthcare technology may allow "smart homes" to identify changes in health status more quickly