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Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors

Nathan W Moon, Paul MA Baker and Kenneth Goughnour

Abstract

The increasing availability of wearable devices (wearables), "smart" home, and other next-generation wirelessly connected devices for work, home, and leisure presents opportunities and challenges for users with disabilities. As augmentative tools for engagement, control, and information, these technologies should not only be usable, but also be accessible and inclusive for people with disabilities. In order to better capture the dimensions of inclusivity of wearable devices, the authors have conducted a review of pertinent literature with respect to a range of representative applications and examples of currently available technologies. Drawing on the findings of the review, the aim of this article is to explore the potential impact of inclusive design principles on future device development for users with disabilities. These observations can help designers incorporate inclusive perspectives into the development process. Such an approach, where people with disabilities constitute an integral part of the development process, will yield products and services that can facilitate increased accessibility, independence, and community participation.

Keywords

Communication, wireless technologies, wearable technologies, disability, design requirements, usability, accessibility

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Introduction

Use of wireless technologies has evolved from simple information connectivity into tools that can enhance community engagement, participation, and self-determined living.[1,2] Wireless connectivity has enabled a new generation of "smart" and connected objects with assistive potential, ranging from wearable computing devices (wearables) worn by individuals to connected physical objects in the environment such as sensors and specialized displays. We refer to this connected ecosystem, in the broadest sense, by the common term "Internet of Things" (IoT). Unfortunately, and as has been the case with previous cases of information technology, design and development has often served to limit the accessibility and usability of these devices. People with disabilities have a range of physical, sensory, and cognitive characteristics. Wearables and, more broadly, IoT devices offer the capability to adapt to individual circumstances, informed by the principles of universal design (UD) originally adopted for the built environment.[3] For the purposes of this review, physical disability may refer to both lower and upper body mobility limitations, including, but not limited to, wheelchair users, users of walking aids, or individuals with spinal cord injuries, cerebral palsy, or injuries or conditions affecting the limbs, hands, or dexterity function. Sensory disability may include, but is not limited to, individuals who are blind or have low vision, individuals who are deaf or are hard of hearing, or individuals with communication disorders. Cognitive disabilities may refer to individuals with developmental or learning disabilities or who may have impaired memory or processing abilities from injuries.

The growing importance of IoT necessitates a proactive vision of wireless technologies and associated

Center for Advanced Communications Policy (CACP), Georgia Institute of Technology, Atlanta, GA, USA

Corresponding author:
Nathan W Moon, Georgia Institute of Technology, 500 10th Street NW, Atlanta, GA 30332-0620, USA.
Email: nathan.moon@cacp.gatech.edu

applications to ensure broader participation by people with disabilities.[4,5] The design of these devices and their services remains largely open and unfixed, thus presenting opportunities for the active participation of people with disabilities, alongside designers, developers, and manufacturers, to address unmet social, cultural, and technical needs.[6] An inclusive design process, taking into consideration the characteristics and needs of a wide range of users, during the conceptualization of the devices, rather than after they have been developed, can proactively address such issues as technology abandonment or discontinuance while enhancing acceptance of these technologies as socially acceptable and culturally appropriate.[7–11]

Methods

In order to articulate the context and factors related to developing inclusive wearable devices, the authors have conducted a review of pertinent literature with respect to a range of representative applications and examples of currently available technologies. A systematic review of the literature was conducted based on a search of academic literature focused on the terms "wearable devices," accessibility, usability, and inclusive design. A set of articles were subsequently identified and analyzed to help generate a baseline of current thought with respect to the parameters typically used in the development of wearable devices. Drawing on the findings of the analysis, this article aims to outline the dimensions of inclusive design principles, and its potential to enhance future device development to have greater usability not just for users with disabilities, but for users in general.

To conduct this review, we performed searches through Google Scholar, ProQuest, Academic Search Ultimate (i.e. EBSCO Academic Search, previously Academic Search Premier and Academic Search Complete), including more focused searches in relevant databases such as ERIC. A list of 20 journals related to the fields of wireless technology, wearables technology, and technology accessibility were used to focus initial findings and to guide cross-references. Relevant search terms and appropriate related terms pertained to technologies (i.e. Internet of Things, IoT, augmented reality, virtual reality, wearables, wireless technology), disability (i.e. blind, low vision, deaf, hard of hearing, communication disorder, aphasia, mobility disability, spinal cord injury), and design (i.e. accessibility, usability, UD). Complex searches were undertaken using appropriate Boolean operators and combinations.

Research inclusion criteria included relevance to the topic, including both wearables or IoT and disability or accessibility. Peer-reviewed and industry studies were permitted, with emphasis on literature from US, UK, and EU-based journals in English. Age of the literature originally was limited to five years and later extended to 10 years. These criteria returned a total of 100 citations, which were further refined to about 50 citations for this study.

Context

With the growing importance of information and communication technologies (ICT) for everyday life, ensuring equal access to electronic information and services is an important area of concern both for persons with disabilities and for society as a whole.[12] These technologies hold great promise for people with disabilities since they have the potential to eliminate (or at least reduce) many of the disabling barriers that impair or completely prevent people with disabilities from participating in many activities. In the United States, households headed by a person with a disability are less likely to use the internet (48%) than households headed by a person without a disability (76%).[13] Inequalities in internet use have been linked to offline social inequalities; for example, people with disabilities who are not online are less well educated and more financially disadvantaged than those who are online.[14] More than 15 years ago, Tim Berners-Lee (2002), creator and director of the World Wide Web Consortium, pointed out, "The power of the Web is in its universality. Access by everyone regardless of disability is an essential aspect."[15] As a result of the aforementioned technical and socioeconomic barriers, people with disabilities are still less likely to use ICT than those without impairments. The ability to connect with anyone, anytime, is among the most important reasons people with disabilities use technologies and are drawn to the world of IoT.[16] "Today's lifelines are advanced technologies, relied upon to conduct daily activities inside and outside the home enabling people to interact anytime from anywhere."[17]

Technologies such as wearables and "smart home" appliances provide new tools and options to increase independence and improve the social and economic participation of people with disabilities.[4] The Cisco Corporation estimates that, by 2020, the number of connected devices in the United States will increase to 4.1 billion.[18] The McKinsey Global Institute projects that, by 2025, the overall impact of these devices on the global economy will be between \$4 trillion and \$11 trillion dollars.[19] The size and import of this market underscore both the need and opportunity for developers and device manufactures to utilize inclusive design to produce more effective products. For individual users, IoT brings useful applications in home automation, security, automated device monitoring, and management of daily tasks.[20] IoT is the next step in a progression of object connectivity, device independence ("smartness"), accessibility, and application. IoT has been referred to variously as a platform (in terms of software that bridges devices, sensors, and data networks, e.g. platform as service), infrastructure (the hardware, routers, fiber and Internet protocols that provide the substrate upon which IoT rests), ecosystem (broadly speaking, the objects and devices that allow users to connect to and use the IoT, including applications, dashboards, analytics, networks, and industries that participate in the development and support of IoT), and framework (typically in reference to the policy and regulatory structures that impact IoT).[21] Given these various definitions, a more nuanced approach to enhancing inclusivity is required—one that includes elements such as privacy, security, data ownership, technology integration, and inclusive design. IoT, most broadly, and wearable devices, more specifically, have the potential to connect people with disabilities with their work, home, and other environments for monitoring, tracking, control, and connectivity, which in turn encourage employment, community participation, and health and functional independence.[4]

While not specifically IoT-based, wearable technologies work synergistically with IoT as part of a new approach to interactivity that can alter how we relate to the physical world. From a policy perspective, increased accessibility of ICT and services in general, and IoT, specifically, has importance as a social design objective to increase participation and engagement. Access to these key technologies can enhance inclusive and independent living for people with disabilities. If proactively designed and developed, wearables and other IoT-based devices can realize their potential to empower all citizens, including people with disabilities to achieve an improved quality of life and greater social and economic inclusion. Connected technologies, such as environmental sensors, smart objects, and wearables, are powerful tools because they can provide the user with a variety of inclusive and assistive information services in real-time.[4] The actualization of this objective has been somewhat complicated by the fact that, although improvements have been achieved in recent years, many device designers and developers still lack a clear understanding of (a) the technical requirements of accessibility and usability, (b) the needs, preferences, experiences and expectations of persons with disabilities, and (c) are not aware of design approaches to address these needs.[6] This diverse demographic includes those with sensory, cognitive, physical, perceptual disabilities, as well as elderly, aging, and those aging into disabilities. This diversity of users increases the challenge, and the need for inclusive policy approaches to the development and deployment of wearable technology. As with the general US population, those with disabilities have become significant users of the Internet and wireless technologies, and hence, by extension, constitute a critical population of users.[22]

A key theme in the literature in the need for IoT and wearables designers to consider how wireless technology design and its responsiveness to social and cultural expectations affects adoption—or rejection—by users with disabilities, to better serve this population.[23] Specific to persons with disabilities, wearable technologies can be powerful assistive tools to increase independence and improve societal participation.[4] While wearables offer great benefits to all, people with disabilities stand to benefit considerably from connected technologies. The tools used to build smarter cities and smarter homes can help create a more accessible environment for people with disabilities, and most importantly, offer them the opportunity to live more independently. A key challenge of technology design is "building in" personalization for people with disabilities, without increasing complexity or decreasing usability. Another significant challenge to wearables specific to people with disabilities is self-management, which refers to the process by which technology manages its own operations without human intervention. By promoting inclusive design and active feedback loops during every stage of technological development, data collection can provide insights into approaches to address the digital divide(s) (as there are many dimensions of on participation) experienced by people with disabilities, and most importantly, lead to the design of appropriate measures to bridge the divide.[12]

Adoption and use vs. rejection and abandonment

Digital technologies offer the opportunity to move away from a "one size fits all" model—especially important as people with disabilities have varied needs and experiences. Thus, technology must be able to adapt to individual circumstances. Another significant challenge to the operation of intelligent devices, specific to people with disabilities, is the idea of "self-management." Here, we refer to the process by which IoT manages its operation without human intervention. By promoting inclusive design and active feedback loops during every stage of device and system development, it will be possible to develop a robust understanding of the digital divide(s) experienced by people with disabilities and to design appropriate measures to bridge them.[12] Smart environments, for instance, can meet the needs of people with disabilities in several different ways: (1) specific interfaces are designed to manipulate home (or for that matter, work) devices for automation and control, (2) special IoT-connected assistive devices can be specifically designed to improve living conditions at home, and (3) smart, context-aware devices reconfigured to meet the unique needs of the user, via sensors, and adaptive intelligence. As such, accessibility and usability are core themes in the development of smart homes and connected communities.

Traditional (preconfigured) UD has demonstrated its success to address users with similar features and needs, but if technology is not capable of adapting to meet the changing needs and context of the user, it may be perceived as inadequate which would likely have a negative impact on consumer acceptance and adoption. In these cases, personalizability has proven to be very effective in providing adaptive services and enabling accessibility to people with disabilities.[24] Smart home initiatives are getting more and more attention from consumers, industry, and government on a global scale,[25] increasing the importance of stakeholder participation from individuals who could especially benefit from these inclusive technologies, including people with disabilities. A wide range of sectors—education, health, security, public safety, business, government administration, and civil society—are taking advantage of technology to reduce costs, bring agility to medical services, achieve a more efficient management and obtain a better quality of life.

Recognizing the vital importance of connectivity and robust information access to innovation, prosperity, education, and civic and cultural life, the US Department of Commerce has made it a top priority to encourage growth of the digital economy while ensuring that the internet remains an open platform for innovation.[26] A number of barriers to this policy objective have been identified in the literature, including economic, awareness, and suitability. Given that IoT devices and internet access are important to such life outcomes as income, mental health, and social capital, having less access to this type of resource may compound the socioeconomic disadvantage that people with disabilities already face.[27] Many who receive assistive technologies simply abandon them when they fail to meet their needs. Two pressing issues especially come to the forefront when it comes to the uptake of assistive technologies: (1) people often lack access to (or awareness of) the technology they need, and (2) technologies, when adopted, frequently are abandoned.[28] In a recent survey of users of the National Health Service (NHS) in Italy, it was found that of the 17% who had abandoned NHS technology, 40% had never actually used it.[29] The World Health Organization estimates that of the 70 million people who need a wheelchair, only 5–15% have access to one.[30] Fortunately, a change in attitudes can be seen related to user characteristics (e.g. disability) and assistive technology usage, where people are now frequently referring to assistive technology as one function of wearable technology. For example, the idea of "wearing my wheels" rather than simply being a wheelchair user.[31] Assistive technology is defined as any product that has as its primary purpose maintaining or improving an individual's functioning and independence, and thereby promoting their well-being.[30]

A number of observers have noted that the reasons for abandonment of wearables and IoT devices are complex, but they frequently reflect a mismatch between user needs and provision. There is a changing paradigm from passive user-centered design of assistive technology, which is now standard as well as best practice, to proactive co-creation.[28] This shift engages the user of the technology in both the design and production processes increases the possibility that consumers will have an end product they are more likely to keep using. This reflects a changing paradigm in disability and design, which when combined with the rise of sensing modalities, allows for a change in the way in which disability is thought of within society. As such, policymakers focused on increasing equitable access, and creators of technologies interested in having their devices used by a larger portion of the population, would both be well served by addressing the specific needs of people with disabilities.[14] For example, an Ubi-Sleeve is currently being developed that would allow prosthesis wearers and clinicians to review temperature, humidity and resulting prosthesis slippage in real-time, as people go about their daily activities.[32]

While there is currently no standard, protocol, or framework defining how the design process should work for wearables and IoT devices, there are many proprietary, protocol-specific and multi-step solutions, for instance, for scanning QR-codes or typing in long passwords. As a result, user experience across devices, even from the same company, can be fragmented. Near field communication (NFC) is one option that can enable a wide range of IoT devices and applications in a smart home.[33] Thanks to their unique features and wide implementation, NFC specifications provide a foundation for an excellent user experience, while extending the smart home ecosystem to unconnected and unpowered devices at a very low cost. Recent advances in IoT combined with reduced costs, improvements in sensor technologies, and a focus on technologies that adapt to user requirements are beginning to improve the landscape of assistive technologies.

Selected wearables technologies and applications

The evolution and spread of wearable technology, facilitated by near ubiquitous connectivity, has complex implications for those who use assistive devices. According to a report by Transparency Market Research, the assistive device market will grow to an estimated $19.68 billion by 2019.[34] This measure only includes devices defined as assistive in a traditional way, while consumer wearables that are useful for the disabled and able-bodied alike would constitute a new category. Although not specifically designated as ‘‘assistive technology,’’ the assistive functionality of wearable devices can nevertheless facilitate the social inclusion and participation of people with disabilities.[23,35] Intelligent devices other than phones and screens—smart headsets, glasses, watches, bracelets—are finding their way into our daily lives. The technology for even less intrusive mechanisms, such as jewelry, buttons, and implants exists, and will ultimately find commercial applications.[24] Popular examples include the FitBit and Jawbone wearable fitness bracelets, which have been available for several years and command the bulk of market share.[36] Wearables, such as Apple Watch, Android Wear and specialized monitoring devices, represent another good source of data that users are increasingly adopting. One of the advantages of these wearable devices is that they can easily become an intrinsic and inseparable part of people with disabilities.[20] Another consideration is the unobtrusive nature of these wearables, which can stream data without hindering the everyday activities of the people with disabilities. Examples such as neuromuscular bions for para- and tetraplegics and radio frequency identification canes, or specialized eyeglass cameras for the blind, are indicative of small devices that can stream huge amounts of data in real-time to various relay and control stations.[37]

In the past several years, IoT-enhanced wearables have come to market specifically as assistive technologies, such as Oticon's Opn hearing aid, which employs the home network to connect other ‘‘smart’’ appliances, ranging from doorbells to smoke alarms, to the user's hearing aids to ensure that they are heard regardless of the user's location in the home.[34] Similarly, OrCam's MyEye is a wearable camera with a mini speaker that can automatically pick up text from the surroundings, recognize people's faces, and ‘‘talk’’ back to the user with the click of a button.[38] Although most wearables are not specifically designated as assistive technology, these devices, sensors, and supporting applications nevertheless can act in assistive and augmentative capacities to facilitate the social inclusion and participation of people with disabilities.[23,35] By connecting a sensing device and monitoring hardware and software, it is possible to measure gait speed, a significant predictor of life expectancy for older adults.[39] Other intelligent devices—smart headsets, glasses, watches, rings, bracelets, etc.—are finding their way into our daily lives. Wearable computing devices such as the Apple Watch and Android Wear currently represent the best known applications of wearables and their potential for users with disabilities.[20] Health and fitness devices, and their applications, could eventually become ‘‘lifestyle remotes,’’ helping users with disabilities control or automate many other systems around them, regardless of whether they are in their homes, offices, or cars.[40]

People with disabilities can benefit from wearable and connected technologies through the specialized human–machine interface (HMI), which refers to an operational subsystem designed to control home appliances and fixtures, such as lamps, televisions, and automatic door openers. Specialized zooming devices (both optical and optoelectronic) allow people with low vision to control the home environment.[41] People with hearing-related disabilities may benefit from specialized HMI that may include touch screens to access graphical information and read text. IoT-based ‘‘smart’’ home technologies can use home networks and cloud-based connectivity to enhance independence and community participation. Currently available voice assistants, such as Amazon Echo, Google Home, and Apple HomePod offer usability for certain disability groups and the potential of programming of ‘‘skills’’ to offer using device programing for control, sensing, and display. Other examples include accessible navigation systems[42] and obstacle detection based on voice-synthesized instructions[43] for blind and low vision users.[41] People with hearing-related disabilities may benefit from touch screens on wearables to access graphical information and text normally presented in auditory formats. People with mobility-related disabilities also can benefit from technologies such as head-tracking signals for tilt-based control of home appliances. Researchers are investigating facial detection, eye-movement control, brain control, gesture recognition, and facial expression recognition for similar purposes.[44] If properly designed, smart home applications are highly capable of improving the autonomy and self-confidence of people with disabilities.[45]

Accessibility/Usability considerations for design and development

As noted previously, designers and developers are not unfamiliar with the concept of usability, but they often lack an understanding of accessibility and the needs of persons with disabilities, or how the concept can work in tandem. Insights gained from employing an inclusive design process can facilitate the training of future designers and encourage responsiveness to the needs and preferences of users with disabilities, while disseminating enhanced methods for effective design. A participatory design process that proactively engages people with disabilities should be employed throughout the design and development phases. Accessibility of future technologies also should become a high-level consideration when planning national technology development strategies and policies. An effective, market-driven approach can enable users to provide input into the device design process.

Users with disabilities should be utilized as participants in the broader deployment process rather than simply being subject to technological change.[23] Integrating UD approaches into development may reduce the need for retrofitting for accessibility. UD may not be sufficient to address social and cultural concerns and the accessibility needs of users with disabilities, but—in tandem with inclusive design involving people with disabilities—it may keep development costs down and allow for new and better methods to emerge.[46] Ideally, inclusively designed IoT integrates design thinking and policy development approaches to generate more cost-effective, flexible, responsive technology outcomes for people with disabilities.[47] By promoting design that is both usable and accessible, technology will better address user needs, and bridge the current gap between what is available and what is needed.

By making input from people with disabilities an integral part of the design process, designers and developers of wearables will be better able to address the importance of accessibility and how it can be incorporated in the creation of connected devices and services.[48,49] Inclusive wearable design integrates design thinking and policy development approaches to generate more flexible, responsive technology outcomes for people with disabilities.[47] Inclusive design can more effectively match technology to user needs and determine how best to design appropriate measures to bridge the current gap. Such a user-centered design process enhances the ability of device and service designers of wearables and other IoT-based devices to apply UD at each step in the process.

Involving people with disabilities early in the design process provides a better understanding of how they engage with these devices and services and what sort of features they could expect to find (step 1). This, in turn, informs how developers specify scenarios and important properties to highlight in the design process (step 2). During the design and implementation stage (step 3), focusing on usability and the technical accessibility of scenarios and devices allows solutions to be evaluated (step 4) with the help of people with disabilities.[46] In effect, efforts to make wearables and related devices accessible and usable for people with disabilities become an integral part of the entire project. If designers and manufacturers fail to consider persons with disabilities during each step of product development, the end product may not meet universally designed criteria, could require costly fixes, and fail to address the needs of a range of market opportunities.[50] Integrating UD into a development process makes it a part of the overall product or service at the outset, rather than addressing the needs of people with disability at the end of the process, or by designing customized, special solutions that involve extra work and resources. This should also help keep development costs down and allow for new and better methods to emerge.[46]

The social and cultural backgrounds of technology users with disabilities, as well as the people who surround them, influence the adoption or abandonment of both assistive technologies and mainstream technologies with accessibility features. While the user and his or her abilities remain the primary focus, other aspects such as language, beliefs, and customs must be taken into account.[51] Users with cultural or linguistic backgrounds valuing acceptance or blending into community may reject devices that draw undue attention. Additionally, disability is frequently framed as a continuum of ability. But differences are not neatly linear, but often highly individualized and specific and may result in the formation of many cultures and communities. Hence, the cultural mores and personal beliefs of technology users must be considered. Technology devices and their modes must go beyond accessibility and usability to consider social and cultural preferences of users, as well as interactions with other individuals. ‘‘One size’’ of technology ‘‘does not fit all’’.[51,52]

As described by Platt (1996), users may come from ‘‘high-context’’ or ‘‘low-context’’ cultures that differ in terms of the value placed upon individuality and independence versus communality and interdependence. For example, individuals with disabilities who have cultural or linguistic backgrounds valuing community acceptance may reject the use of devices that draw undue attention. For these individuals, technologies to be used in public settings must easily accepted by others. Researchers have called attention to the need for ‘‘culturally responsive’’ and ‘‘culturally sensitive’’ approaches to technology decision making,[8,9] which may be extended to include mainstream technologies with accessibility features and their design. In addition, researchers also have noted the potential of ‘‘cultural probes’’ to include ‘‘unconventional end-users in a formative process of design’’ in order to help match technologies to user needs and to empower users rather than foster dependence on new technology.[7]

Identifying key stakeholders

Daily life in the modern world has become increasingly reliant on digital technologies. This evolution has facilitated countless new opportunities and has enabled the development of extraordinarily innovative products and services to meet individual and collective demands. Findings from the literature suggest that personal data, processing power, and connectivity are the basic building blocks of this digital world.[53] In the interests of both citizens and industry—on local and global levels—the expected benefits of IoT must also respect the many accessibility, privacy, and security challenges inherent in its myriad systems. Data losses, infection by malware, unauthorized access to personal data, intrusive use of wearable devices, and unlawful surveillance are some of the many risks that IoT stakeholders must address to attract prospective end-users of their products or services.[53] Accordingly, prudent policy development suggests an intentionally wide range of stakeholders be consulted to devise uniform application of a legal data protection framework, as well as the development of tools to ensure a high level of protection for personal data.[53] Compliance with this framework is key to meeting the legal, technical, and fundamental human rights' protections the societal challenges described above represent for vulnerable populations.[53] In order to accomplish the above, it will be necessary to define, identify and engage the primary stakeholders in the IoT environment (See Table 1). Various participants have interests in this process. For example, the European Data Protection Working Party divides IoT stakeholders into device manufacturers, social platforms, application developers, other third parties, and IoT data platform developers.[53]

One of the major concerns from the viewpoint of device users in the IoT environment is that the data processed/analyzed for provisioning of services can be distributed to secondary and tertiary operators, potentially compromising an individual's right to informational self-determination.[54] This is exacerbated by current business models in which end-users might not even be aware of this sharing of data, which complicates the issue of informed consent. Conversely, from the operational standpoint, the cyber workflow point of view, wearables and other connected devices must also satisfy such requirements as real-time, robustness, reliability, resilience, privacy, and security to have a sustainable, long-term social impact. System requirements (e.g., real-time, robustness, security) represent major though addressable, challenges for the cyber-workflow stages (e.g., data collection, analytics, comprehension, actuation stages); requirements which need to be satisfied in an end-to-end manner while ensuring seamless integration into existing community testbeds and environments.[55] Finally, users must be made aware of the consequences of use and given control of their personal data throughout the product lifecycle, and when organizations rely on consent as a basis for processing, it should be fully informed, freely given and specific.[53]

Methodologies and approaches for inclusive design

Focus groups and cultural probes

As previously mentioned, adoption and use, as well as rejection and abandonment, of technologies by users with disabilities is not purely a matter of technical accessibility and usability. Focus group methodologies may query on current-market technologies to ascertain barriers and facilitators—factors that might prevent future wearable technologies from being adopted and establish specific use cases that might support adoption and use of prospective devices. These methods also may uncover

Table 1. Stakeholders for the design of wearables for users with disabilities.

People with disabilities	• Potential consumers of wearables • Wearables (and IoT more generally) may allow for greater civic and community participation
Wearables designers	• Wearables that are responsive to user needs and feedback are more likely to succeed.
IoT & wearables manufacturers	• The IoT market is rapidly expanding
Retailers	• Currently not filling the needs of a potentially large segment of the population. • Retailers as intermediaries between producers and consumers of wearables, with an important role of education and outreach regarding accessibility and usability
Policymakers	• Greater societal participation by people with disabilities offers great benefits.
First responders/health professionals	• Continuous/more frequent health monitoring can allow for more specialized and less frequent visits from health care professionals. • More immediate notification of changes to health data.
Employers	• Wearables may enable accessibility and inclusion of workplaces as workplace accommodations.

unmet needs, latent demands, and user expectations—how currently available devices support physical accessibility and community participation, and, just as importantly, how they do not. A similar approach has been espoused in "design thinking",[56] which integrates starting points for systematic innovation among designers and engineers. Technology development should take into account the emotional meaning of things as well as their functional performance. Whether described as "latent needs," users may not always be able to articulate how technologies may improve accessibility, integration, participation, or otherwise enhance their lives—this potential must be observed and discovered. Once identified, these observations can be translated into insights and opportunities, which may be translated into products and services.

Heuristics and usability evaluations

Usability testing is one of the most widely used and important methods for evaluating product design.[57] Usability is the effectiveness, efficiency, and satisfaction that specified users can achieve specific goals in an environment. In order to provide assessment criteria for measurable performance assessments, it may be possible to adapt standardized principles of usability for online user interfaces:[58,59]

- Visibility of system status—whether users are informed with appropriate feedback and within reasonable time (i.e. How do input information into your wearable?)
- Match between system and the real world—whether the device the user's language, with words, phrases and concepts familiar to the user and in a natural order (i.e. how well does the intelligent agent understand you?)
- User control and freedom—whether users choose system functions by mistake and have a clearly marked "emergency exit," and whether undo and redo are supported adequately (i.e. what happens when you make a mistake and need to go back?)
- Consistency and standards—whether platform conventions are used and different words, situations, or actions to mean the same thing are avoided (how does your use of your wearable compare to your smartphone?)
- Error prevention—whether the device eliminates error-prone conditions or alternately present users with a confirmation option before they commit to any action (i.e. does the device confirm before you make a command? Has it accidentally done things you did not want?)
- Recognition rather than recall—whether device minimizes the user's memory load by making objects, actions, and options visible, and whether instructions for use of the system are visible or easily retrievable whenever appropriate
- Flexibility and efficiency of use—whether the courseware system can cater to both inexperienced and experienced users, and allows users to tailor frequent actions
- Aesthetic and minimalist design—whether the device avoids information which is irrelevant or rarely needed (i.e. how do you deal with many different streams of information in your wearable device?)
- Recognition, diagnosis, and recovery from errors—whether error messages are expressed in plain language, precisely indicate the problem, and constructively suggest solutions
- Help and documentation—whether help and documentation are needed and provided as appropriate.

Wizard-of-Oz simulation

To investigate wearable computing use cases in realistic contexts, a "Wizard-of-Oz" (WOz) simulation[60–62] is a technique where subjects are told that they are interacting with a computer system through a natural-language interface (NLI), though in fact they are not. Instead, the interaction is mediated by a human operator, the "wizard," with the consequence that the subject can be given more freedom of expression, or be constrained in more systematic ways, than is the case for existing NLIs. In the case of design for users with disabilities, WOz simulations may allow participants with disabilities to experience potential wearable devices and services as part of the prototyping phase. The "wizards" simulate the behavior of a theoretical intelligent computer application with involvement of subjects to observe the use and effectiveness of proposed devices and services to be developed, especially in situ (in actual physical locations while carrying out actual primary tasks, often with confederates, bystanders, and other participants). This allows designers and engineers to obtain information regarding the realities of prospective technologies, as well as facilitate design guidelines for wearable systems, insights into the needs of future wearable service authoring tools, and identification of where technical innovations are needed for users with disabilities.

Augmented reality for design

It is common for designers to feel that they do not have enough information about users' needs.[63] This is especially true at the front end of the design process when many different ideas for a product are considered.[64] Data are often gathered based on some representation of a product concept. The general understanding is that the more realistic the product representation the better the input that can be elicited from a user. There is an element of communication here between users and designers. A designer will obviously try to be as clear as possible to communicate how features of interest should work. However, there is often information that is "sticky"[65] in both directions. It can be hard for a designer to understand what a user wants and hard for a user to understand what a designer intends. A design artifact (sketch, rendering, model, etc.) is often used to facilitate this understanding. This is a particular challenge when (1) developing novel and innovative products for new technologies such as products for managing IoT devices and validating that they are accessible and barrier free,[66,67] and (2) designing for users whose individual characteristics are not easily standardized for accessibility, such as users of complex rehabilitation technologies or users with multiple disabilities. Numerous design process methods have been developed over the years to streamline new product development. While these improvements are important, the overall market success rate of new products has not changed much over the last 25 years.[68] Companies have become more efficient at developing new products, but they are not necessarily more successful. A largely unexplored area is the reliability of user/stakeholder input that is gathered and used during the design process. Augmented reality (AR) may be one tool for soliciting early design input and usability evaluation for people with disabilities.[69,70] AR refers to a view of real or physical world in which certain elements of the environment are computer generated. When viewed through a camera/display, software can replace or add elements to a product to modify or completely update the look/configuration. AR can be a useful tool since it is quick and easy to create digital models of a product concept or interface early in the design process compared to a physical prototype. If testing based on this type of product representation is shown to be valid, it may significantly increase a designer's ability to obtain reliable information about a product very early in the design process and identify design/usability problems when they are much easier to fix or explore more radical/transformative design ideas than would otherwise be feasible.

Conclusion

While many companies—including device manufacturers, handset manufacturers, networks, and application developers and other organizations recognize the importance of wearable device usability, considerably less make an inclusive design process central to device development. In order to create a supporting IoT that works for everyone, accessibility and more broadly, usability, needs to be considerations during each stage in the development process. Active user involvement becomes particularly important when designing applications to be used by people with disabilities due to their specialized user requirements as well as applicable regulations, standards, and guidelines.[71] Accessibility, usability, and we argue, the ultimate objective—inclusivity, rely on many factors to be in place, including guidelines for standardization and interoperability of devices, the extension of broadband internet networks, protection of privacy, improved security of data, and a commitment to accessibility by all parties.[72] Despite these challenges, it is important not to lose sight of the significant benefits that wearables may confer, especially to often overlooked populations, such as people with disabilities. If industry stakeholders incorporate UD and inclusive design that involves active participation of people with disabilities, wearables, "smart" home devices, and other IoT objects and services will offer greater independent living, more personalized care, more flexibility and mobility, and better employment and education outcomes through next-generation wireless technologies.

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Guarantor

NWM

Contributorship

NWM and KG researched the literature and conceived the study. KG wrote the first draft of the consultation with PMB and NWM. NWM and PMB were responsible for developing conclusions and recommendations. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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ORCID iD

Nathan W Moon https://orcid.org/0000-0003-4982-0758

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