Designing Wearable Technology for an Aging Population

Accommodating age-related deficits in hearing, memory, and fine-motor control can result in life-improving wearables for a growing population.

By Joanna E. Lewis & Mark B. Neider

FEATURE AT A GLANCE:
When considering the future and application of wearable technological devices, the growing demographic of adults over the age of 65 should be included during the product design process. Wearable technology could provide an ideal mechanism for delivering supportive applications to a growing older adult population, but designers must consider age-related changes in cognitive, sensory, and motor function when developing for older populations. Potential issues with wearable devices for older adults can be avoided by acknowledging limitations, and development teams can create effective and safe platforms that appeal to a variety of end users.

KEYWORDS:
wearable technology, aging, older adults, mobile devices, product design, cognition, memory, sensory processes, usability, vision, hearing, aging decrement

For the past several years, wearable devices have been heralded as one of the next great technological frontiers. By what amounts to turning a computer into an accessory, users can interact with their favorite technological gadgets without the need to hold the device. Interaction between the user and the device happens via tactile, voice, or other physiological means (e.g., a sensor on the device to measure the user's heart rate). Furthermore, these devices promise to be *intelligent*; they can track environmental conditions using various sensors, such as user location through GPS, and provide context-appropriate information. These wearable gadgets may be worn on the wrist, mounted on the head, or attached to clothing.

A goal in designing these devices is to provide seamless technological integration with people's daily lives. These novel, unobtrusive devices are typically smaller than a smartphone yet may provide important information on a moment-by-moment basis to a user throughout the day.

Users of these technologies vary widely across a number of important factors. Here we focus on both the challenges and opportunities that developers face in appealing to older adult users. On the one hand, wearable digital technology can provide an assistive mechanism for attenuating age-related decline in areas such as memory function. On the other hand, poor consideration of usability factors associated with age can render the benefits of usage moot and negatively affect technology adoption.

Best-practices guidelines have been offered for display design in the contexts of what we refer to as "one-and-done" interaction devices (or interfaces), such as automated teller machines or Web sites (e.g., Morrell, 2002; Rogers & Fisk, 1997), whereby a user accesses the device, gets what he or she needs, and disengages the device. However, such guidelines are largely absent in the case of wearable devices, which can be constantly engaging the user and present different opportunities and limitations in the interaction domain (such as reduced screen space to present information).

Although many design guidelines might transcend domain, consideration of the factors unique to wearables is likely to produce the best products. And designing with older adults in mind can improve both utility and adoption rates while reducing user frustration (Fisk, Rogers, Charness, Czaja, & Sharit, 2009; Mead, Batsakes, Fisk, & Mykityshyn, 1999). In this article, we aim to evaluate this specific population with regard to cognitive, physical, and sensory abilities as related to wearable devices. Based on this evaluation, we make some design suggestions to be considered in future development.

WHY SHOULD WE DESIGN WEARABLE TECH FOR OLDER ADULTS?

Critically, the older-adult demographic group is one that is expanding rapidly (see Figure 1); the U.S. Census Bureau estimates that the population over 65 years old will double from 2012 to 2050, to approximately 83.7 million in this cohort (Ortman, Velkoff, & Hogan, 2014). This growth, fueled by the baby boomer generation, represents a sort of change from the norm in that baby boomers have the potential to be comfortable and savvy with technology (Mihailidis,

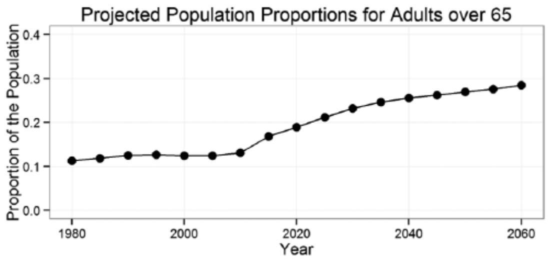

Figure 1. Proportion of the population estimated or projected to be over 65 between 1980 and 2060. Source. U.S. Census Bureau, Population Estimates: Historical Data and 2014 National Population Projections.

Cockburn, Longley, & Boger, 2008), increasing the likelihood that they will continue to be users as they age and making them an important demographic group for developers of wearable technology to consider. This is particularly likely to be the case in "early" older adulthood; it is unclear whether baby boomers will remain up-to-date with emerging technologies as they advance in age. Fortunately, a good deal of both basic and applied research exists from which we can begin to make some design recommendations in this context.

Designers and programmers can create wearable technology solutions that can alleviate some of the hardships that begin to arise with age, but this goal is not without challenges. Generally speaking, an older adult needs more time to complete a given task compared with a younger adult. However, the trajectory and nature of age-related cognitive and motor decline is highly variable across individuals (Fisk et al., 2009).

What we do know is that even in normal aging, most individuals experience some degree of impairment in overall cognitive function on measures related to processing speed, attention, and memory (Salthouse, Atkinson, & Berish, 2003). These aspects of cognition are necessary for a functional and independent lifestyle, and decline can translate into poor performance of typical everyday tasks.

A common example is the management and memory for daily medication regimens: Adults over the age of 65 are responsible for about 40% of all medication consumption (American Society of Consultant Pharmacists, n.d.) and have the highest rate of medication usage (Kaufman, Kelly, Rosenberg, Anderson, & Mitchell, 2002). Given age-related decline in the processes associated with organizing and adhering to a medication regimen, this challenge seems like a golden opportunity for wearable technology to provide a way to improve the lives of older adults. A simple device that remains with the individual throughout the day, stores associated medication frequency and specifications (e.g., instructs not to take with food, provides a picture of the pill to be taken at a specific time), and is not intrusive to daily activities might mitigate these issues.

There are other clear and intuitive examples of how wearable devices might be used to improve health and general wellness in older populations. Individuals can wear sensors to track various health matrices (such as cardiac health); aid in rehabilitation and treatment evaluation; identify potential illness; monitor for safety concerns, such as falls; and serve as emergency alert systems (Baig, Gholamhosseini, & Connolly, 2013; Czaja, 2015; Patel, Park, Bonato, Chan, & Rodgers, 2012). Fitness-tracking watches could help encourage older adults to monitor physical activity and sleep behaviors.

Similarly, shoes have been developed to monitor the gait of older adults. This type of passive device can be informative for treatment, diagnosis, and fall prevention, without requiring active interaction. For example, a wearable shoe sensor enables the measurement of gait characteristics associated with Parkinson's disease. Such measurements can be used not only for the detection of symptoms but also to evaluate the efficacy of treatment (Mariani, Jiménez, Vingerhoets, & Aminian, 2013).

Additionally, technology can provide solutions to social isolation commonly seen in this population by providing additional avenues to connect with friends and family (Cotten, Anderson, & McCullough, 2013; Czaja, 2015). Although there are clear examples of wearable devices that can assist older adults, poor design decisions can undermine benefits if the devices are inaccurate, too difficult to use, or overly cumbersome. As such, in laying out a framework for design guidelines, we focus on three broad aspects of human function that are known to change with age: cognitive, physical, and sensory.

BRAIN MATTERS

Executive function. Executive function comprises a collection of cognitive processes (e.g., attention, working memory, and decision making) that are vital to higher-order human behavior (Salthouse et al., 2003). A large body of evidence indicates that executive function is particularly vulnerable to age-related decline (Salthouse et al., 2003). This vulnerability is evident at the neural level; the prefrontal cortex (a brain region thought to underlie executive function) tends to lose tissue volume with increasing age at a disproportionate rate relative to many other brain structures (Haarmann, Ashling, Davelaar, & Usher, 2005; Salthouse et al., 2003).

Accounting for the decline in executive function is crucial for design when considering older adult users. Older adults are likely to have difficulties with technologies that rely heavily on actively maintaining task status. Ideally, information maintenance should be offloaded to the device whenever possible. For example, Mynatt, Melenhorst, Fisk, and Rogers (2004) developed a technological aid to assist with the cooking process. This system relieves the user of having to remember completed tasks and future actions required to complete a meal (Mynatt et al., 2004) and serves as a good model in designing for older adults.

An additional concern tied to executive-function decline relates to multitasking with technology. This type of activity, whereby a user attempts to manage competing demands from concurrent tasks, relies heavily on executive-control processes. Kramer and Larish (1996) noted a common finding across many studies of multitasking and aging indicating that the cost of performing multiple tasks at the same time increases with age. That cost can be represented by increases in the time required to complete overlapping tasks, increased errors, or both.

Designers should consider the potential increase in processing demands on the given user when multiple tasks are required to be performed in overlapping time frames and attempt to minimize such occurrences and provide adequate time to complete a task if temporally constrained.

Memory. Despite common misconceptions that memory deteriorates with age, memory decline in older adults varies for different types of memory. For example, there are likely to be issues in recalling a person's name or the time of a previously scheduled appointment (referred to as *explicit memory*) as well as particular events in one's life (referred to as *episodic memory*). However, older adults are less likely to have issues with learned or automatized memory-related actions, such as knowing to pick up the phone when it rings (referred to as *implicit memory*).

More specifically, decay has been observed in explicit and episodic memory, but implicit memory systems appear to be relatively spared from age-related decline (Craik & Jacoby, 1996). Decline in explicit memory is typically observable in situations that are based on free recall (Craik & Jacoby, 1996). For example, needing to remember how to access an e-mail account or application on a mobile device would be more difficult, as it relies on having to remember from explicit memory how to execute the task step by step. Designers can alleviate such problems by providing cues that are event based rather than time based (e.g., "take your medication when the device beeps" as opposed to "take your medication at 8:00").

Designers need to remain aware of possible memory limitations and how they might be related to remembering how to complete a task or any associated training. Therefore, designers may need to provide cues or supplemental instructions throughout the training or duration of given task.

GETTING PHYSICAL

Motor control. As previously mentioned, the ability to perform various motor-related tasks may change with age. During the course of normal aging, gray matter volume decreases in brain structures associated with coordinated and controlled movement (Seidler et al., 2010). Illnesses (e.g., Parkinson's disorder, multiple sclerosis, Huntington's disease) can further exacerbate motor-control decline, and conditions such as arthritis may limit movement because of inflammation and pain.

Along these lines, approximately 50% of adults over the age of 65 (Centers for Disease Control and Prevention, 2013)

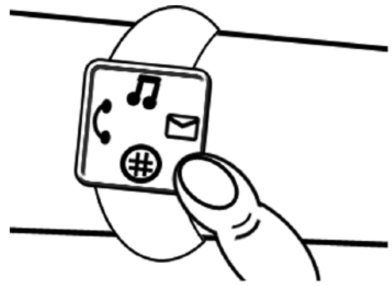

Figure 2. Graphic of a generic smart watch design demonstrating the small scale for the user's available tactile interaction.

suffer from some form of arthritis, indicating that designers should nearly always account for some difficulty in movement when considering older adult users. The most important consideration here for designers is that fine motor control declines with age (Seidler et al., 2010). Given that many devices require fine, coordinated motor actions, such as gesture or button selection for interaction, this change is one that warrants particular consideration.

Additionally, older adults are less sensitive to tactile feedback or touch-based stimuli, which are imperative for interacting with technology (Fisk et al., 2009). As such, wearable devices should have appropriately sized buttons, dials, and calibration for detecting gestures to accommodate a range of age demographics, particularly older users. Devices designed for this target population should avoid interfaces that necessitate fine motor skills to operate, such as what smart watches often require (see Figure 2).

An alternative to using interfaces that require fine motor control is using voice-commanded technology. For example, software has been developed that enables users to control their home computer via voice and reduces the need to interact with a mouse or keyboard. Such interfaces might prove ideal for older adults with clinical limitations to movement, allowing for increased accessibility to technology for this population. Google Glass is an existing example of wearable technology that can be controlled using voice and minimal gestures (i.e., sweeping gestures as opposed to fine movements; see Figure 3).

JUST MAKES SENSE

Vision: Acuity. A common and nearly ubiquitous change that occurs during aging is diminished visual acuity. Nearly all adults require intervention to correct vision as they age. In many cases this requirement is caused by changes in ocular musculature that make it more difficult to bend the lens of the eye to accommodate nearby stimuli (e.g., reading glasses for presbyopia). Others are associated with abnormal changes in the eye itself, such as cataracts or macular degeneration.

Wearable technologies have the potential to be limited in this case because they rely heavily on visual information. Be it

Figure 3. User wearing Google Glass and contacts. Photograph by Beth Lewis.

Figure 4. A user wearing a fitness tracker device without a display on the band. This device relies on connection to a smart device, which would be easier to view and interact with when need be. Photograph by Beth Lewis.

by design or by necessity, visual information tends to be presented in the smallest way possible to minimize the size and weight of the device. For example, a smart watch designed to be lightweight and comfortable requires a relatively small display, one that could be difficult for older adults to read with ease. Fisk et al. (2009) recommended that a four-letter word should be roughly the width of a thumb when the arm is extended (visual angle of 0.6°), which may be hard to achieve on small wearable devices.

Even when users have corrected-to-normal vision, there is the potential for glasses to interfere with use. For example, head-mounted displays can be rendered useless to individuals wearing eyeglasses because of the cumbersomeness and possible visual occlusion from having both the device and glasses on the user's head at the same time. Design considerations need to be made for users with less-than-perfect vision – in this context, that group includes nearly every older adult user.

One good example already in practice is the integration of optional prescription frames for the Google Glass device. This adaptability to the user's needs is the type of design approach we suggest that designers of wearable technology adopt. Additionally, devices may integrate the option to adjust text size or all together eliminate the need for text in daily use (e.g., fitness trackers without a display on the tracker; see Figure 4). At the very least, making text size customizable by the user is a good design practice that holds up particularly well for older adults, given what we know about changes in visual acuity. However, it can be challenging to implement this feature in devices with little screen space (e.g., smart watches).

Overall, designing for changes in visual acuity represents a formidable challenge, and developing novel ways of providing information to older adult users that can be deciphered without perfect visual function is likely to be a worthwhile endeavor moving forward.

Vision: Peripheral. Decrements in peripheral vision are less obvious than those associated with acuity but no less important. It has been well documented that older adults in particular exhibit decreased sensitivity to information occurring outside of central vision (Ball, Beard, Roenker, Miller, & Griggs, 1988). This issue raises two important concerns in the context of interface design. First, when designing for older adults, the amount of time that older adults must spend fixating on a given display is time that they are likely to be less sensitive to potentially informative stimuli that might appear in peripheral visual areas. Independent of age decrements, when engaged with a central task, people demonstrate decreased awareness of the surrounding environment (Miura, 1990). This decreased awareness could be a safety concern when engaged in tasks such as driving.

Second, older adults are likely to be less sensitive to visual cues presented in the periphery. That is, if designers wish to alert an older adult user to information presented in the periphery (perhaps in the context of head-up displays), the alerting cue will likely need to be more robust to attract the attention of an older adult compared with a younger adult. In both cases, steps should be taken to account for age-related changes in peripheral vision to maximize intended technology-related benefits for older adult users.

Hearing. Wearable devices do not rely exclusively on touch and sight for interaction; auditory interaction is often employed as well. For example, smartphones can respond to a user's verbal commands, a feature useful for hands-free interaction, given that the user does not have to be looking at or even holding the phone. Also, systems may use auditory warning signals to alert the user that there is an error, possible

Table 1. Technology Design Recommendations for Wearables Intended for an Older Population

Consideration	Limitations	Suggestions
Motor	Diminished fine-motor control	Increase the size of buttons and icons. Controls should be easily adjusted with minimal force. Tasks requiring fine-motor control should allow for easy recovery from errors. Guard against activation of nontarget controls.
	Tactile sensitivity	Limit need for tactile feedback in device interactions.
Vision	Acuity	Text should be easily legible with minimal correction. Text size should be modifiable. Provide a text-to-speech option for small text size.
	Periphery	Reduce the need to rely on cues in the periphery; use alternative sensory inputs (e.g., auditory or tactile). Adjust content/text size according to eccentricity from the center of the screen. Minimize time on task.
Eyeglasses	Visual occlusion	Make devices and displays adaptable to the user (e.g., adjustable display location).
	Discomfort	Design devices that accommodate eyeglasses.
Hearing	Frequency, vocals	Use alert tones at frequencies that are less vulnerable to age-related decline. Provide customizable volume, particularly for speech or other high frequencies. Allow for calibration of volume at specific frequencies.
Executive function	Complex tasks/ functions Working memory	Minimize the steps required to complete a given action. Provide the user with the status of the steps or goals within broader tasks, such as showing the user the next action.
	Distraction	Minimize instances in which multiple tasks overlap in time and compete for attention. Keep task-irrelevant information to a minimum.
	Processing speed	Older adults need extra time to perform various tasks or no time constraints at all.
Memory	Explicit memory decline	Offer cue information needed to execute a task, and make future tasks event based and not time based. Minimize the number of steps (recall) needed for a task.

danger, or some other form of worthwhile information toward which attention should be directed. However, with normal aging, atrophy occurs in the cells in the cochlea (the primary detecting agent for incoming auditory signals) as well as other parts of the auditory sensory system. Many of the cells that atrophy are responsive to specific frequencies associated with everyday functioning and human speech (McCoy et al., 2005; Wingfield, Tun, & McCoy, 2005).

Designers should limit the use of higher frequencies for conveying information to older adults and, when needed, bolster the amplitude of these frequencies to offset age-related decline. To accommodate such adaptive approaches, devices may incorporate a sort of "hearing test" to calibrate a given device's output signal to the particular user. Ideally, this feature could be performed occasionally at home. More generally, providing users with easily adjustable volume controls that can be adjusted on the fly to suit users' needs across changes in function and environments is advised.

DESIGN SUGGESTIONS

Understanding the challenges with which older adults must contend during normal everyday functioning will enable designers to develop wearable devices that are not only easier for older adults to use but potentially *more useful* for older adults as well. Still, compared with younger adults, older adults tend to experience feelings of mistrust and frustration when using novel technologies, resulting in disuse (Fisk et al., 2009; Mynatt et al., 2004). Consequently, older adult adopters of such technologies might face stigmatization from their peers. Such instances of stigmas associated with wearable devices have already been noted in the context of Google Glass (Google, 2013). Similarly, some assistive devices, such as hearing aids, carry with them an implicit association with negative age-related stereotypes; novel wearable technologies could fall prey to the same sorts of associations. Thus consideration should also be given to the social implications that might come along with using wearable technologies by this age demographic.

For example, designers should avoid overly clunky or unfashionable devices that may make older adults feel that they are different from everyone else or designs that might be associated with a stigma of limitations in old age. Designing with increased sensitivity to the needs of older adult users is likely to increase adoption of wearable technology by this growing demographic group. We have provided a list of particular issues in regard to older adults that developers should consider during the design process as well as suggestions to address these concerns (see Table 1).

Considering these limitations and recommendations during the design process will improve the usability of wearable technology for a growing population of adults 65 and older. Although members of this population historically have been characterized as hesitant to adopt technology, designers of wearable technology may be able to overcome this demographic trait by developing devices that are useful, comfortable, and easy for senior citizens to interact with.

Broadly speaking, the older adult population is one that could potentially benefit considerably from wearable devices that offer support for some of the declines normally experienced with age. All in all, the potential synergy between older adult users and wearable technologies is one that should encourage developers to design strategically and older adult users to strongly consider adoption of these assistive devices as they emerge.

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