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Forum

Advancing the Aging and Technology Agenda in Gerontology

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Interest in technology for older adults is driven by multiple converging trends: the rapid pace of technological development; the unprecedented growth of the aging population in the United States and worldwide; the increase in the number and survival of persons with disability; the growing and unsustainable costs of caring for the elderly people; and the increasing interest on the part of business, industry, and government agencies in addressing health care needs with technology. These trends have contributed to the strong conviction that technology can play an important role in enhancing quality of life and independence of older individuals with high levels of efficiency, potentially reducing individual and societal costs of caring for the elderly people. The purpose of this "Forum" position article is to integrate what we know about older adults and technology systems in order to provide direction to this vital enterprise. We define what we mean by technology for an aging population, provide a brief history of its development, introduce a taxonomy for characterizing current technology applications to older adults, summarize research in this area, describe existing development and evaluation processes, identify factors important for the acceptance of technology among older individuals, and recommend future directions for research in this area.

Key Words: Aging, Technology, Health, Well-being

Interest in technology for aging is driven by multiple converging trends: the rapid pace of technological development, particularly in consumer electronics and communication; the unprecedented growth of the aging population in the United States and worldwide; the increase in the number and survival of persons with disability; the growing and unsustainable costs of caring for the elderly people; and the increasing interest on the part of business, industry, and government agencies in addressing health care needs with technology. Taken together, these trends have contributed to the strong conviction that technology can play an important role in enhancing quality of life (QoL) and independence of individuals with impaired functioning due to trauma, chronic disorders, illness, or aging. Moreover, the hope is that this can be achieved with high levels of efficiency, potentially reducing individual and societal costs of caring for the elderly people (Schulz, 2013; Pew Research Center, May 2014, "The Internet of Things Will Thrive by 2025." Available at: http://www.pewinternet.org/2014/05/14/internet-of-things/). For healthy older individuals, technology may delay or prevent the onset of disability, stimulate new activities and interests, facilitate communication, enhance knowledge, elevate mood, and improve psychological well-being. From our perspective, the critical question is not *whether* this will happen, but rather how best to shape and direct our efforts to optimize the development and application of new technologies.

In keeping with the goals of the "Forum" section of *The Gerontologist*, the purpose of this article is to articulate a "well-documented argument presenting a viewpoint on a topical issue," in this case, aging and technology. We define what we mean by technology for an aging population, provide a brief history of its development, introduce a taxonomy for characterizing current technology applications to older adults, summarize research in this area, describe existing development and evaluation processes, identify factors important for the acceptance of technology among older individuals, and recommend future directions for this area.

What Do We Mean by Technology for Older Adults?

Although we tend to think of technology in terms of advanced scientific knowledge used for practical purposes, technology is more broadly defined as the making, modification, and usage of tools, machines, techniques, systems, and methods of organization, in order to solve a problem, improve a preexisting solution to a problem, achieve a goal, handle an applied input/output relation, or perform a specific function (Schatzberg, 2006). Recent advances in technology are based on the digital revolution, the shift from analog electronic and mechanical devices to the digital technology that enables computers, smartphones, the internet, robots, and a myriad of sensing and actuating devices. We have coined the term Quality of Life Technologies (Kanade, 2012; Schulz, 2013) to describe novel, intelligent technologies specifically designed to affect the QoL of individuals who use them. Thus, QoL technologies are person- and/or context-aware technologies that *maintain* or *enhance* the physical, cognitive, social, or emotional functioning of humans. Note that this broad definition includes not only systems that are compensatory or assistive (e.g., assistive technology) but also technologies that are preventive and that entertain and stimulate, elevate mood, or improve psychological well-being as well as those that facilitate information seeking and sharing, social connectedness, and the performance of tasks including work tasks or everyday activities.

Technologies for older adults are the subset of QoL technologies that (a) take into account life-span developmental changes in sensory-motor functioning, cognition, and motivation, and (b) address issues of major concern to both older individuals and society such as health, functioning, autonomy, and psychological well-being. QoL technologies for older adults also include technologies that empower informal caregivers to provide support to older adults.

A Brief History of Research on Aging and Technology

The emergence of technology and aging as a research enterprise in gerontology can be traced to parallel developments on three continents. Early work in this area was carried out in the United States by Koncelik (1982) who published a book on "Aging and the Product Environment" as part of an environmental design series. This was followed by the work of Robinson and Birren (1984) on "Aging and Technological Advances" and Fozard and Fisk's (1988) "Human Factors and the Aging Population." Some of the best early empirical work in this area was carried out by Charness and colleagues (e.g., Charness, Schumann, & Boritz, 1992) on computer use of older adults, Rogers and colleagues on automatic teller machine use among older persons (e.g., Rogers, Gilbert, & Cabrera, 1997), and Czaja and colleagues on older adults and workplace technologies (e.g., Czaja & Sharit, 1998). A milestone in terms of articulating a technology perspective in aging was the publication of a chapter on "Human Factors and Design for Older Adults" in the third edition of the *Handbook of the Psychology of Aging* (Charness & Bosman, 1990). The early forays into technology and aging in the United States were strongly influenced by human factors research and its application to aging, and this theme is the primary focus of the National Institute on Aging funded Center for Research and Education on Aging and Technology Enhancement (CREATE) established in 1999 (Czaja, Sharit, Charness, Fisk, & Rogers, 2001).

A second line of research on aging and technology emerged in Europe at about the same time under the leadership of Bouma and Graafmans, who published an influential book called *Gerontechnology* (Bouma & Graafmans, 1992) in which they describe a new interdisciplinary academic and professional field combining gerontology and technology. The International Society for Gerontechnology (ISG) was founded in 1997 and the journal *Gerontechnology* was established soon thereafter.

Less well known are the efforts of Asian scientists and professional societies in promoting the aging technology agenda with the development and implementation of technologies to assist older people in their homes as well as residents of long-term care facilities. For example, in Japan, the idea of using robots as household helpers for older adults dates back to the 1980s, and regular use of robot pets in long-term care settings emerged in the early 1990s (Wagner, 2009). Notably, Asian researchers have emphasized robot technology as providing solutions rather than merely enabling assessment, and they recognized early on the market potential of these strategies for supporting older adults (Kohlbacher & Hang, 2011).

In sum, interest in aging and technology research has existed since the late 1980s in various parts of the world, and the field has continued to grow since then (e.g., Charness & Boot, 2009; Rogers & Fisk, 2010; Schulz, 2013). For example, at the 2013 meeting of the Gerontological Society of America, we identified seven symposia and two paper sessions explicitly addressing technology and aging issues. Despite this growth, the field continues to be amorphous and fragmented, lacking a clear conceptual basis, distinct identity, and future direction. More specifically, the field continues to struggle with various definitions of what gerotechnology is and how the wide array of such technologies may be categorized. In addition, possibly because of its location at the intersection of multiple diverse scientific disciplines such as psychology, computer science, human factors engineering, and design science, it has been difficult to establish generally agreed-upon methodological standards for evaluating technology. Finally, at the conceptual level, technology and aging research is rarely linked to established life-span development theories, making it difficult to integrate this area into mainstream gerontology. In what follows, we address some of these issues in hopes of providing some direction to the field.

Existing Technologies: Suggesting an Organizing Scheme

The proliferation of QoL technologies and their application has resulted in a parallel increase in concepts, labels, and definitions. Making sense of or organizing families of technologies into coherent categories is an important but as yet unmet goal in this area and contributes to fragmentation of this field. An agreed-upon classification system for QoL technologies would facilitate communication among researchers, clinicians, and other stakeholders; enable appropriate comparisons between competing technologies; help with the identification of appropriate evaluation metrics; and identify gaps in existing research.

Many organizations such as the International Organization for Standardization (Bougie, 2008) and the U.S. Food and Drug Administration have weighed in on the definition and classification of technologies designed to enhance health and safety and improve QoL. Advocacy groups such as the American Association of Retired Persons (Barrett, 2008) and The Center of Aging Services Technologies have also attempted to organize the vast number of QoL technologies into a few coherent categories. More recently, researchers have focused on the development of taxonomies specifically aimed at bringing order to technologies used in telemedicine and ehealth (Bashshur, Shannon, Krupinski, & Grigsby, 2011). Although there is a great deal of variability in these classification systems, they all emphasize the functional domain addressed by the technology as a primary organizing heuristic.

Based on existing classification approaches, old and more recent, we have identified five core life domains with high levels of intrinsic value that have been the focus of technology development to date and are likely to continue to be targets for future development (Table 1). They include (a) physical and mental health; (b) mobility; (c) social connectedness; (d) safety; and (e) daily activities and leisure. Note that these are not mutually exclusive categories, as for example, improving social connectedness and safety is also likely to improve health and well-being. Note also that cognition is a core capability that supports functioning in all of these domains. Viewed from a fundamental conceptual perspective, technologies that support these domains play the important role of supporting health, functioning, and psychological well-being in the context of age-related declines.

A related and cross-cutting attribute of technology concerns the functional processes or methods used to achieve improvement in the five life domains. These include (a) monitoring or measuring the environment or the individual; (b) diagnosing or screening to identify problems, needs, or desires; and (c) treating or intervening to address identified problems, needs, or desires. Technologies are available to monitor individual health and support mobility, social connectedness, safety, and daily and leisure activities. The availability of contextual data by which to infer the condition of an individual and/or her/his environment (e.g., in-home temperature and light conditions) may be used by a range of external entities (e.g., a heath surveillance program; caregivers of demented older adults) and motivate or change the behaviors of targeted individuals. These same data can also be used to detect adverse changes in physical health conditions early or screen for risk factors such as risk of falling or having an automobile accident. Finally, technologies are available to deliver a wide variety of treatments and interventions to manage chronic disease, support self-management, provide decision support, provide coaching to mitigate risk, enhance social integration, address safety concerns, and provide task assistance for daily activities. Examples of research on technologies for each of the 15 cells of the matrix presented in Table 1 can be found in the literature.

Table 1. Technology Applications to Important Life Domains

Technology functions	Life domains				
	Physical and mental health	Mobility	Social connectedness	Safety	Everyday activities and leisure
Monitoring/ measurement (person, environment)	Physiological functioning (e.g., heart rate, blood pressure, and oxymetry), affect, health behaviors	Speed and variability of gait, distance covered, vestibular functioning, driving behavior, daily exercise	Frequency and duration of mobile and fixed communication device uses; frequency and duration of time in direct communication with other humans; frequency and time spent in social settings	Frequency of falls, location, driving ability	Frequency, accuracy, and speed of daily task performance; frequency and duration of leisure activities
Diagnosis, screening	Clinical conditions, risk status for clinical conditions	Risk for falling; ambulatory ability, adequacy of daily physical exercise	Social isolation, social integration	Emergency situation, being lost, at risk for driving accidents	Critical cognitive functioning, critical ADL/IADL status
Treatment, intervention (compensation, prevention, enhancement)	Remote behavioral treatment, chronic disease management, prevention and wellness interventions, clinical decision support	Guidance assistance, risk mitigation (e.g., risk of falling), encouragement and support for exercise	Enhanced social integration, connectivity through computers/communication technologies	Emergency response systems, computerized driving assistance, alert systems	Task assistance or training, entertainment, education

Note: ADL = activities of daily living; IADL = instrumental activities of daily living.

To date, the vast majority of research in this area falls within Column 1 of the matrix, technologies aimed at maintaining, improving, or enhancing the health of older individuals. This includes the literature on telehealth, ehealth (electronic health technologies), and mhealth (mobile health technologies). A wide variety of measuring or monitoring devices are currently available in the health domain, including ambient sensing systems that monitor type and frequency of activity in homes or long-term care facilities, wearable sensors that can measure physical activity, heart rate, blood pressure, and temperature, and freestanding devices that can be used to assess multiple physiological parameters such as blood pressure, blood oxygen, or wound healing. These systems can be used to inform an older individual or a clinician about the status of an individual on any of these dimensions, detect significant changes, and may motivate interventions to address a problem identified by the monitoring system. These same monitoring systems can also provide formal diagnostic feedback and decision support, informing an individual that his blood pressure is high or his blood oxygen saturation level is low, either directly or via a clinician who monitors the data being generated.

Technology can also be used to deliver interventions such as remote behavioral treatment of depression via computers or handheld devices or chronic disease management through guided coaching programs that encourage medication, diet, and exercise adherence. Wearable and embedded sensors, GPS systems, driving monitors, and communication devices can also be used to assess the ambulatory ability and location of an individual, their degree of social isolation, driving ability, and accuracy and speed of everyday task performance. This diagnostic information can in turn be used to tailor technology-based interventions, which might include increased connectivity through computers or other communication devices, emergency response systems, or task assistance and training provided by robots or computerized coaches.

How Well Does Technology Work in the Context of Aging?

Applications of technology for maintaining or improving physical and psychological and more recently cognitive health are ubiquitous and represent one of the most heavily researched areas in technology and aging. Remote monitoring, telecommunication strategies, and disease management technologies have been applied to multiple chronic illnesses common among older individuals, such as chronic obstructive pulmonary disease, diabetes, heart failure, hypertension, and psychiatric conditions. Indeed, we have not only multiple reviews of literature in this area (Hailey, Roine, & Ohinmaa, 2002; Roine, Ohinmaa, & Hailey, 2001; Wootton, 2012) but also reviews of reviews (Ekeland, Bowes, & Flottorp, 2010).

Evidence for positive effects of telemedicine (e.g., effective treatment and disease management) include online psychological interventions, management of chronic heart failure and respiratory conditions through remote monitoring, telepsychiatry, home telehealth for diabetes, and internet and computer-based cognitive behavioral therapy for the treatment of anxiety and depression. However, these positive outcomes should be viewed cautiously as many of these findings are based on studies considered to be of poor quality (Ekeland et al., 2010; Wootton, 2012). Studies are often based on small, select samples, are short in duration, examine a limited number of relevant outcomes, and are typically not carried out as randomized trials.

Examples of recently completed high-quality studies in this area include the Whole System Demonstrator Trial (Steventon et al., 2012, 2013) and the study by Chaudhry and colleagues (2010) on telemonitoring in patients with heart failure. The Whole System Demonstrator Trial found small differences favoring the telehealth condition in hospital admissions and mortality (Steventon et al., 2012), but no significant differences in patient reported health-related QoL, anxiety, and depression. Chaudhry and colleagues (2010) also tested a telemonitoring intervention versus usual care in a randomized trial of patients who had recently been hospitalized for heart failure. No differences were found in readmissions and mortality, the primary endpoints of the study. When viewed together, these studies suggest that the beneficial effects of telemonitoring are at best modest, a conclusion that can be broadly applied to telehealth in general (e.g., Ekeland et al., 2010).

The literature on the application of technology to other life domains of older adults is less robust. Researchers have repeatedly demonstrated their ability to *monitor* and in some cases diagnose an individual's ability to ambulate, their social connectedness or isolation, and their performance of everyday activities, but little is known about our ability to affect *changes* in these domains using technology. For example, researchers have used imbedded sensors in both homes and long-term care facilities to monitor changes in ambulatory ability including older adults with dementia (Slaughter, Estabrooks, Jones, & Wagg, 2011; Topo, 2009). These systems can reliably detect changes in performance, but to date we have not been able to interpret these changes in ways that would allow prediction of an adverse event such as a fall that might be avoided with appropriate intervention. In a similar vein, efforts to develop coaching systems that monitor a task such as meal preparation and provide guidance when the individual deviates from the appropriate protocol have had mixed success (Godwin, Mills, Anderson, & Kunik, 2013; Topo, 2009). Note that many of these technologies can benefit not only the older individual but also informal caregivers who may use them to ease the burden of caregiving (Carretero et al., 2013), but here, too, rigorous evaluations are lacking. To be fair, many of these technologies are still in the early stages of development, and they continue to improve at a rapid pace. Existing research provides important insights on how to refine and apply these technologies to the lives of older individuals.

On the whole, strong studies such as randomized trials demonstrating the efficacy or effectiveness of technology-based approaches to domains other than health are very rare. Whether or not such studies are needed to advance this area is open to debate (see Riley, Glasgow, Etheredge, & Abernethy, 2013). Some of the disadvantages of randomized trials are that they are time consuming and expensive to carry out. In contrast, the pace of technology development is very rapid. Thus, evaluating a given application over a 5-year period, the typical duration of a randomized trial, has the potential of yielding nonmeaningful results because the technology is typically obsolete by the time the study ends. More agile evaluation strategies are needed. These might include methods for rapid testing with small samples and retesting as the technology evolves. Despite the lack of compelling evidence about the efficacy of many technologies currently available in the market place, industry is aggressively marketing these technologies, sometimes with outlandish and distorted claims about their efficacy. To date, market penetration of technologies for older persons is still limited, which may be a consequence of the lack of convincing cost-effectiveness data. However, the continued growth of this industry suggests widespread belief in the potential of these technologies to fundamentally enhance the QoL of older persons.

Although older individuals, particularly those over the age of 75, have historically been late adopters of widespread technologies such as the internet, smartphones, tablet PCs, and social networking services, these technologies play an increasing role in maintaining and promoting their health and well-being (Gell, Rosenberg, Demiris, LaCroix, & Patel, 2013; Pew Research Center, April 2014, "Older Adults and Technology Use." Available at: http://www.pewinternet.org/2014/04/03/older-adults-and-technology-use/). As market penetration of these devices and services reach future cohorts of the elderly people, they will become increasingly important. Cisco estimates that there were 13 billion internet-connected devices (e.g., phones, chips, sensors, and implants) in 2013, and this will grow to 50 billion in 2020 (Pew Research Center, May 2014, "The Internet of Things Will Thrive by 2025." Available at: http://www.pewinternet.org/2014/05/14/internet-of-things/). This will result in a global, immersive, ambient computing environment with advanced connectivity between devices, systems, and services that will alter everyday life for individuals of all ages. Among the many derivative consequences of a computerized world will be applications that serve the unique needs of older persons.

Developing and Evaluating New Technologies

Product development and evaluation processes must be closely aligned to optimize the development of new technologies for older individuals. For example, a recent systematic review notes that acceptance and adoption of health technologies is often hampered by usability problems (e.g., technology is not perceived as useful or easy to use), pointing to the importance of determining the most effective development processes to address these issues (Jimison et al., 2008). Figure 1 illustrates the development process beginning with assessment of user needs drawn from epidemiological and survey findings and human factors and human–computer interaction methods such as task analysis and contextual inquiry. This is typically followed by the development of a design prototype guided by end-user input, followed by a robust prototype that can withstand anticipated real-world conditions and a laboratory prototype that can be tested with targeted end users. Note that all of these activities take place in the laboratory and include small numbers of end users participating in the design and development process. A wide variety of qualitative methods can be used at this stage of development, including storyboarding (McGee-Lennon, Smeaton, & Brewster, 2012), scenario testing (Spinsante, Antonicelli, Mazzanti, & Gambi, 2012), Wizard of Oz studies (conducted with a man-behind-the-scenes operating a system that appears to be fully functional but, unbeknownst to the end user, is not; Heerink, Kröse, Evers, & Wielinga, 2006; Kelley, 1984; Liu et al., 2008), focus groups and in-depth interviews (Gövercin et al., 2010; Han, Lee, & Song, 2013; Tan, Ng, Wong, & Kiat, 2012), and so forth, to answer questions about factors such as usability, learnability, acceptability, reliability, effectiveness, efficiency, and satisfaction (Nielsen, 1993; Figure 1). Assuming that the technology meets criteria for acceptability, safety, and effectiveness in the laboratory, it is then ready to be deployed in the field of testing, pilot trials, and in some cases, randomized efficacy, effectiveness, or comparative effectiveness trials. Findings from these studies help inform the commercial viability of the system in that they provide information on whether or not potential users are willing to adopt the system, how it affects their QoL, and whether it has societal benefits such as reduced health care utilization and cost. An important

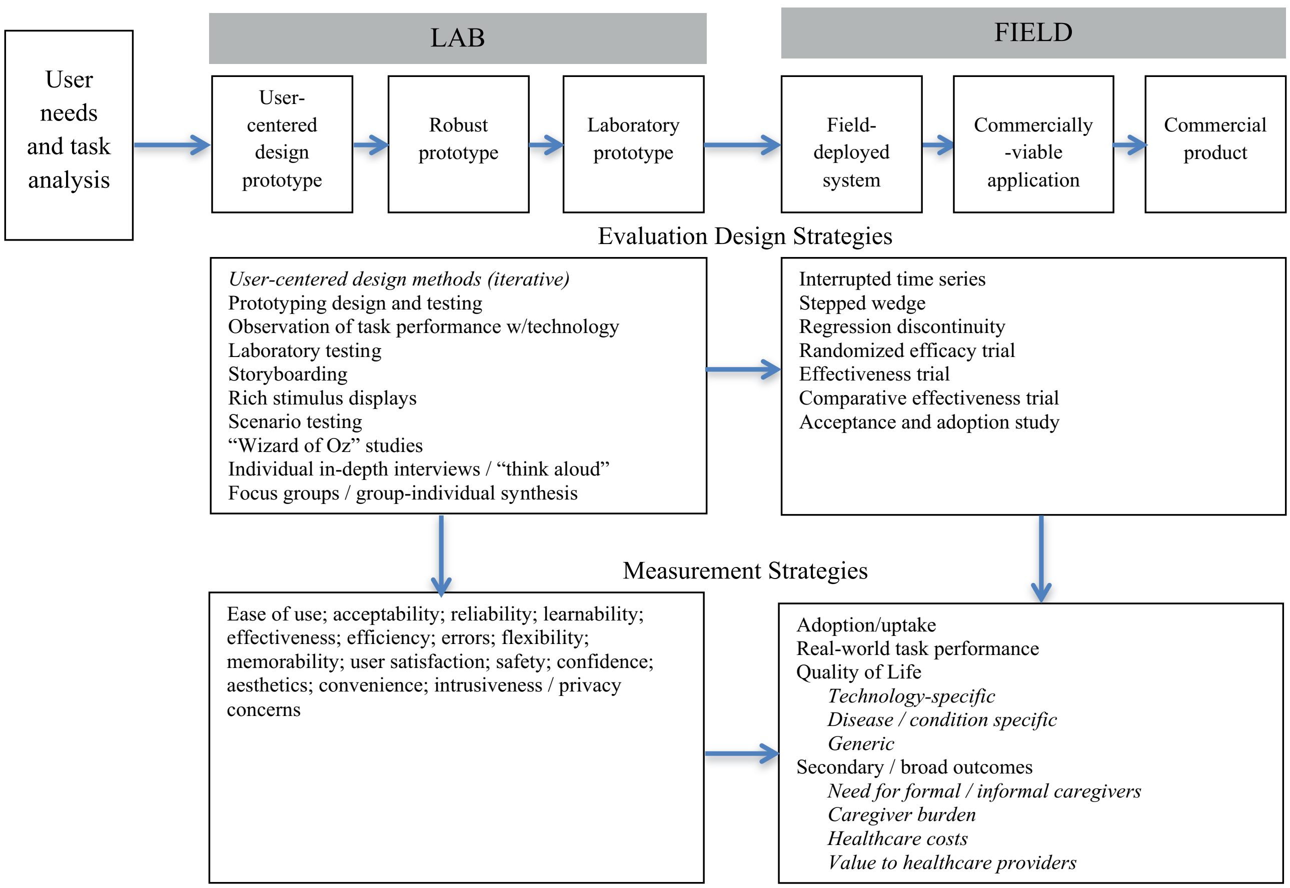

Figure 1. Technology development and evaluation process.

component of this process is identifying all potential user groups and ensuring that they are represented in the design and evaluation process (see Fisk, Rogers, Charness, Czaja, & Sharit, 2009).

Because this process is notoriously slow and costly, researchers have become interested in finding ways to speed up the development (e.g., rapid prototyping) and evaluation process by emphasizing less rigorous evaluation methods (Riley et al., 2013). This is particularly important for technology applications because of the rapid pace at which technology advances. Thus, iterative small sample intervention testing can be an effective means for quickly improving a technology. Alternatives to randomized controlled trials that emphasize within-participant approaches such as interrupted time series, stepped wedge, and regression discontinuity designs may also be effective in accelerating the development and evaluation process (see Riley et al., 2013). Ultimately, the choice of evaluation method should be determined by the question being addressed and the level of evidence needed to build a compelling case for adopting a new technology.

Technology Use in Older Adults As a Conceptual Challenge for Gerontology: Linking Technology Use With Life-Span Development and Aging Theories

Existing conceptual models in technology and aging have appropriately focused on the question of technology uptake. Over the last several decades, scholars, designers, and practitioners have sought to understand the factors that influence technology acceptance and adoption in general (Czaja et al., 2006; Davis, 1989) and acceptability and effectiveness of consumer health technologies in particular (Rogers & Mead, 2004). What are the facilitators and barriers of technology uptake at both the individual end user and societal level? To varying degrees, existing models have focused on the following three factors: (a) abilities, needs, and preferences of end users; (b) features of the technology; and (c) societal factors, including social and health policy, and the regulatory environment. For example, the original technology acceptance model (Davis, 1989) broadly argued that perceived usefulness and ease of use were key to predicting intent and actual technology use. The technology acceptance models have evolved to include additional predictors, including age, as presented in the unified theory of acceptance and use of technology (and most recently, the Consumer Acceptance & Use of Information Technology Model; Venkatesh, Thong, & Xu, 2012). Rogers and Fisk (2010) have emphasized age-specific models focused on the interplay between age-related declines in sensory, motor, and cognitive abilities and the design of technology that recognizes or adapts to the functional capabilities of the end user. More recently, the CREATE team has expanded this concept to include the importance of the social and environmental context of the individual as well as available support systems (Figure 2). Our own work draws attention to implicit cost–benefit calculations carried out by end users, including costs such as loss of privacy, expense, reduced efficiency, reduced social interaction, stigma, and training and maintenance requirements and benefits such as enhanced functioning, increased

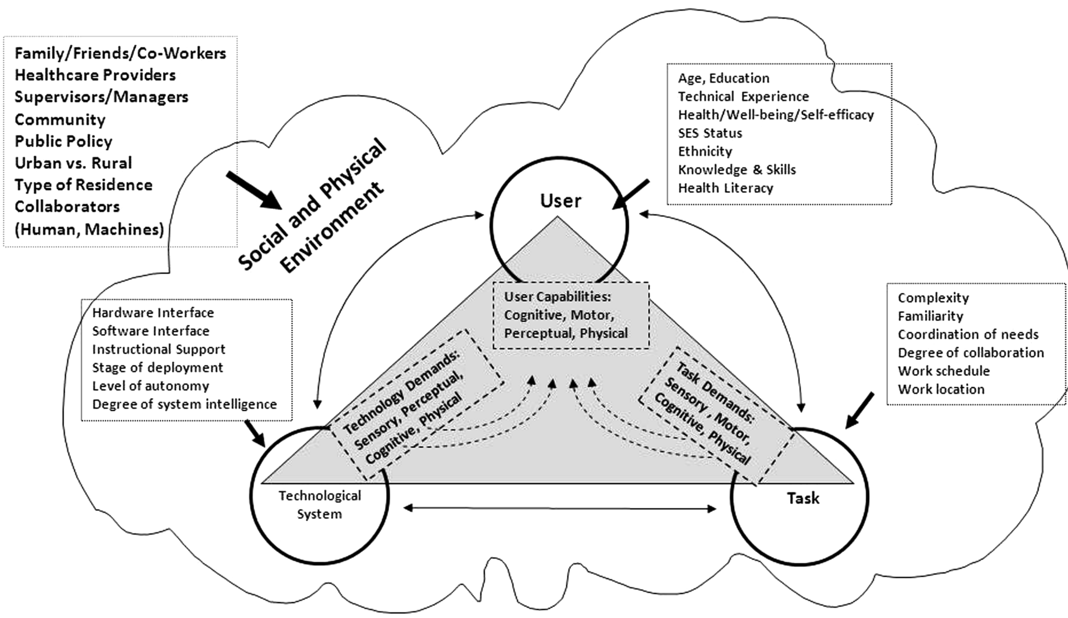

Figure 2. Center for Research and Education on Aging and Technology Enhancement model of human/technology interactions.

autonomy/independence, reduced burden on others, better health, and enhanced safety (Schulz, 2013).

Despite the central role of age-related factors in some technology uptake models, the role of technology in the broader context of aging and life-span development is not well developed. In order to emphasize the potential role of technology in main stream gerontology, we examine subsequently the role that technology might play in existing theories of life-span development such as the Socialemotional Selectivity Theory (Carstensen, 2006), Selective Optimization with Compensation (SOC) Theory (Baltes & Baltes, 1990), and Life-Span Theory of Control (Heckhausen, Wrosch, & Schulz, 2010). We chose these three theories because of their focus on late life processes that are central to aging, their broad appeal to the gerontological community, and their status as mainstream conceptual frameworks for understanding developmental regulation. In addition, all three theories assume that developmental growth is possible even in advanced old age. The Socialemotional Selectivity Theory maintains that with increasing age, people become increasingly selective, investing greater resources in goals and activities that maximize positive emotional experiences, and minimize emotional risks. This begs the question, how might technology support or optimize these goals? Technology can facilitate selection of desired people and contexts that support positive emotional interactions and help promote entertaining and engaging experiences. Conversely, this theory can also inform the design of technology, suggesting that failure experiences in learning or using a technology may be especially distressing to older individuals, leading to rejection of the technology.

The SOC Theory focuses on how individuals allocate resources to promote growth and maintenance of functioning in the face of age-related declines/losses. According to the SOC model, successful aging involves *selection* of appropriate functional domains on which to focus one's resources, *optimizing* developmental potential (maximization of gains), and *compensating* for losses—thus ensuring the maintenance of functioning and a minimization of losses. Lindenberger, Lövdén, Schellenbach, Li, and Krüger (2008) use this general framework to discuss how intelligent assistive technology that continuously adjusts the balance between environmental support and individual capabilities can maximize the potential of an individual by "combining support with challenge, thereby enhancing motivation, social participation and a sense of autonomy" (p. 63).

The Motivational Theory of Life-Span Development proposes that the key criterion for adaptive development is the extent to which the individual realizes control of his or her environment (i.e., exerts primary control) across different domains of life. Striving for primary control is a constant and universal motivational drive throughout the life course. However, as individuals' capacity for primary control decreases in old age, and some goals become unattainable, individuals need to have strategies that facilitate disengagement from unattainable goals in favor of pursuing other more attainable ones. A wide variety of cognitive strategies can be used to navigate these transitions, including adjusting expectations, values, and attributions so that losses in primary control do not undermine the individual's motivational resources for primary control striving in general. Technology can compensate for declining primary control abilities through assistive and support devices, enhance control striving through task performance feedback that optimizes motivational engagement, and facilitate disengagement from unattainable goals by identifying appropriate alternative goals for a given level of functioning.

Common threads in all three of these theories is the need to allocate diminishing resources resulting from age-related declines in sensory, motor, and cognitive abilities; strategies for compensating for losses; and methods for optimizing adaptive development. We have provided a few examples of how technology might play a role in each of these areas, but much more needs to be done to spell out the conceptual linkages between technology, human development, and models of successful aging. In this regard, these theories may be particularly useful in helping us understand when reliance on technological aids depletes resources through protracted disuse of skills and abilities, undermines motivation, and engenders loss of autonomy.

Moving Forward: Future Directions

Successful technology development requires unprecedented interdisciplinary collaboration. As gerontologists, we are accustomed to working in interdisciplinary teams, but the development of successful technology requires teams that not only include clinicians, social and behavioral scientists, and policy experts but also include engineers, human factors specialists, computer scientists, designers, and informaticists.

Integrating technology into existing organizations, operational systems, and the workflow of clinicians is at least as challenging as developing the technology itself. We tend to think of technology as freestanding devices that help accomplish specific tasks. In order to be truly effective, the monitoring, diagnostic, and treatment technologies envisioned for older persons need to be integrated into existing health and social service systems and in many cases family systems. Just as important, they ultimately need to fit seamlessly into older adults' daily lives. Alternatively, existing operational systems need to be changed in order to accommodate technology.

The biomedical research model for evaluating the efficacy or effectiveness may not be the optimal choice for technologies that change at a rapid pace. Organizations such as Medicare and private insurers are reluctant to adopt and pay for technology without compelling cost–benefit and cost-effectiveness data. Generating such data often requires lengthy and costly randomized trials, which technology developers cannot afford. Smaller scale, rapidly executed studies or demonstration projects should play a major role in the technology development and evaluation process.

Theoretical models that drive the technology research agenda should go beyond describing facilitators and barriers to technology uptake. Who and why older individuals adopt and/or abandon technology are important questions, but many other relevant issues have received little attention in the literature. Earlier in this article, we provided some examples regarding the role of technology in several popular theories of life-span development, but much more needs to be done to bring technology into mainstream theories that drive gerontological research.

Technology can be helpful by maintaining functioning, independence, and motivating engagement with important life goals, but it has also been speculated that it can be harmful by eroding skills and abilities through disuse, undermining motivation, and compromising autonomy and independence and by promoting a false sense of security. Little research is available to address this issue. Researchers should be sensitive to and assess these potential negative outcomes as they strive for technologies that hit the "sweet spot" of maximizing well-being and functioning through technology without undermining the future performance potential of the individual.

Technologies to support older individuals will continue to be developed and marketed with or without our input. As gerontologists, we have an important obligation to help optimize the development process and serve as gatekeepers of the evidence base regarding their effectiveness. These are important functions that will accelerate the development and dissemination of cost-effective systems that enhance the functioning, QoL, and independence of a rapidly growing older population.

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