EMERGING TECHNOLOGIES TO SUPPORT AN AGING POPULATION

A Report by the

TASK FORCE ON RESEARCH AND DEVELOPMENT FOR TECHNOLOGY TO SUPPORT AGING ADULTS

COMMITTEE ON TECHNOLOGY

of the

NATIONAL SCIENCE & TECHNOLOGY COUNCIL

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About the Task Force on Research and Development for Technology to Support Aging Adults

The Task Force was established under the NSTC Committee on Technology to examine the potential of technology to maximize the independence of aging Americans by increasing opportunities for social engagement and connectivity as well as reducing the impact of any cognitive and physical limitations.

About this Document

This report identifies a range of emerging technologies that have significant potential to assist older adults with successfully aging in place, each categorized by their role in supporting a set of primary capabilities. It identifies a number of focus areas that could support each capability and provides recommendations for research and development (R&D) that are required to develop key technology solutions over the coming decade. Cross-cutting topics that affect multiple capabilities are also discussed. These recommendations are offered as a guide for both public and private sector R&D. The overall goal is to improve the quality of life, enhance individual choice, reduce the financial and emotional burden of care to individuals and families, and reduce the burden of providing care on the American healthcare infrastructure.

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* *As affiliated at the time each member contributed to this report.*

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List of Abbreviations and Acronyms

ACL	Administration for Community Living
ACS	American community survey
AD	Alzheimer's disease
ADL	activities of daily living
AHRQ	Agency for Healthcare Research and Quality
CFPB	Consumer Financial Protection Bureau
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DOT	Department of Transportation
eCare	electronic care
FCC	Federal Communications Commission
FDA	Food and Drug Administration
GPS	global positioning system
HHS	Department of Health and Human Services
HIPAA	Health Insurance Portability and Accountability Act of 1996
HUD	Department of Housing and Urban Development
IADL	instrumental activities of daily living
IT	information technology
IoT	internet of things
MCI	mild cognitive impairment
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
ONC	Office of the National Coordinator for Health Information Technology
OSTP	Office of Science and Technology Policy
R&D	research and development
SSA	Social Security Administration
TAAG	Telecommunication Act Accessibility Guidelines
TRL	technology readiness level
VA	Department of Veterans Affairs
WCAG	Web Content Accessibility Guidelines
USDA	United States Department of Agriculture

Executive Summary

The U.S. Census Bureau projects that the number of people in the United States aged 65 or older will grow to 95 million by the year 2060 and comprise nearly a quarter of the population. The combination of the projected growth of this segment of the population and the desire of many older Americans to live independently in their homes and communities makes it critical that the Federal Government proactively develop strategies, tools, and recommendations to enable them to live healthy, independent lives. The Task Force on Research and Development for Technology to Support Aging Adults was established under the NSTC Committee on Technology to examine the potential of technology to maximize independence for older Americans by sustaining health, independence, and opportunities for social engagement.

This report identifies a range of emerging technologies that have significant potential to assist older adults, and it is offered as a guide for both public and private sector research and development (R&D) to improve the quality of life, enhance individual choice, reduce caregiver stress, and cut healthcare costs. The Task Force identified six primary functional capabilities as being critical to individuals who wish to maintain their independence as they age and for which technology may have a positive impact.

1. **Key Activities of Independent Living.** Living independently requires the ability to perform of a range of activities that impact our daily lives. Many of these activities can be assisted through technology, including those that support good nutrition, hygiene, and medication management.
2. **Cognition.** Cognitive changes are common during aging, with increasing prevalence at older ages—varying in severity and impact. These changes can affect the ability to live independently as well as personal safety. Technology holds the promise to help older adults monitor changes in their cognition, provide mental training to reduce the impact of these changes, and create systems that assist individuals and families to maintain financial security.
3. **Communication and Social Connectivity.** Older adults may face communication challenges as the result of hearing loss, social isolation, and loneliness, especially in economically distressed and rural communities. Technology can improve hearing and strengthen connections to larger communities.
4. **Personal Mobility.** Mobility is a key factor in successful aging. To live independently, an individual must have the ability to comfortably and safely move around the home and throughout the larger community. Technology can assist older adults in staying mobile and able to safely perform key activities necessary for day-to-day life as well as interact with their communities.
5. **Transportation.** True independence requires mobility outside of the home and neighborhood. Transportation needs and limitations are dictated to an extent by the changes to individual physical and cognitive abilities that come with age. While some older adults remain completely independent and continue to drive without assistance, others may be able to drive but require vehicle modification and/or advanced technologies to assist them while operating a vehicle. New technologies could also help older adults more safely and easily use public transportation.
6. **Access to Healthcare.** Access to healthcare plays a critical role in helping older adults stay active and independent as they age. Activities and strategies that support the maintenance of function and independence with age are multifaceted. Alignment and coordination of these efforts through technology can increase the effectiveness and efficiency of these services.

In the process of identifying primary capabilities and focus areas in which technological advances can have a positive impact in enabling older adults to age in place, several areas emerged that are associated with a number of technological solutions and were therefore not specific to individual R&D recommendations. These areas are included in the final section of the report, **Cross-Cutting Themes**.

I. Introduction

The number of Americans aged 65 or older is growing rapidly—increasing by 40% between 2000 and 2016 to approximately 50 million people, over 15% of the total population[1]—and is expected to grow to nearly a quarter of the population by 2060.[2] For older Americans living outside of a nursing home, 25% of those aged 65 to 74 and 50% of those aged 75 and older have reported some kind of disability, such as problems with vision, hearing, or mobility.[3] The combination of the projected growth of this segment of the population and the desire of many older Americans to live independently in their homes and communities makes it critical that the Federal Government proactively develop strategies, tools, and recommendations to enable older Americans to live healthy, independent lives for as long as possible.

> "We're on the verge of new technological revolutions that could improve virtually every aspect of our lives, create vast new wealth for American workers and families, and open up bold, new frontiers in science, medicine, and communication." – President Donald J. Trump[4]

The Trump Administration has made finding solutions for an aging population a research and development (R&D) priority.[5] The overarching goals of this R&D should be to enhance the functional independence and continued safety, well-being, and health of older Americans, while reducing overall economic costs and the stress on the Nation's healthcare infrastructure. Achieving these goals will:

- improve the quality of life and continued contributions of active and independent individuals to the greater community and the economy;
- enhance individual choice with respect to living arrangements;
- reduce the financial and emotional stress on informal and unpaid family caregivers; and
- reduce the cost to the American healthcare system, including not only hospital and nursing home expenses, but also expenses related to long-term care services and support.

While the primary purpose of this report is to broadly identify for both public and private sector stakeholders the R&D that is needed to create technology to support an aging population, the capabilities enabled by such technology also hold promise to improve and enrich the lives of all Americans with challenges common in older adults, such as mobility, social connection, cognitive changes, and general health and nutrition. The development of technology to assist older adults is a large and rapidly growing industry that could be accelerated by R&D in areas highlighted in this report.

Scope and Organization of This Report

In preparing this report, the Task Force first identified the primary capabilities that older adults must maintain to continue to live independently (e.g., the ability to perform the Key Activities of Independent Living), as well as more focused areas deemed key to those capabilities and most likely to benefit from advances in technology (e.g., hygiene, nutrition). It then reviewed a diverse spectrum of emerging technologies and systems designed or with the potential to maintain those capabilities within each

[1] https://www.census.gov/newsroom/press-releases/2017/cb17-100.html

[2] https://www.census.gov/newsroom/press-releases/2018/cb18-41-population-projections.html

[3] http://www.disabilitystatistics.org/StatusReports/2016-PDF/2016-StatusReport_US.pdf

[4] https://www.whitehouse.gov/briefings-statements/remarks-president-trump-american-leadership-emerging-technology-event/

[5] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf

area. Based on this review and a subsequent gap analysis, the Task Force identified functional needs (e.g., maintain oral health) that could potentially be met by new technological advances (e.g., develop systems to support personalized dental regimens) and the R&D required to develop those technology solutions over the next five to ten years. This report and the technologies discussed herein do not represent a comprehensive review of the current state of each field but are intended to highlight a range of promising and/or key technologies in each of the focus areas of the report.

In addition to scientific and engineering research needed to further the development of the technology itself, the report includes recommendations for research necessary to inform the development of standards and policies. In addition, the report notes a number of social and behavioral science factors that will impact acceptance and implementation of new technologies. Achieving all of these advances will require partnerships between the public and private sectors for both R&D and implementation, with the private sector leading the way in product development and deployment.

The Task Force recognizes that the abilities of individuals and their needs for technology will vary significantly—both within the population and for individuals over time. Age-related changes in cognitive and physical abilities are not static and, in some cases, may be either transient (e.g., movement limitations following joint replacement) or time-variable (e.g., sundowning phenomenon of dementia). Therefore, the ability to monitor and assess the needs of aging individuals over time, and to identify appropriate technologies or adapt technologies to these changing needs, will be key to each of these areas of technology R&D and implementation. In addition, the needs of older adults living at home are expected to differ from the general population, and research targeted at identifying these unique factors is recommended such that appropriate and optimized solutions can be developed.

The report discusses six *primary capabilities* identified as being critical to individuals who wish to maintain their independence as they age and for which technology may be able to have a positive impact, as well as a set of cross-cutting themes relevant in all or most of the six primary areas:

- Key Activities of Independent Living
- Cognition
- Communication and Social Connectivity
- Personal Mobility
- Transportation
- Access to Healthcare
- Cross-Cutting Themes

Each primary capability is divided into a group of *focus areas*. Each focus area includes a set of *key functional needs* that are ripe for innovative technology solutions, followed by a *bulleted list of recommended R&D topics* needed to develop those solutions.

II. Key Activities of Independent Living

The ability to live independently requires performance of a range of activities. These key activities are called the Activities of Daily Living (ADLs) and include eating, bathing, dressing, toileting, transferring, walking, and managing continence.[6] Instrumental ADLs (IADLs) are another category of activities necessary for functioning in community settings and include cooking, driving, using the telephone or computer, shopping, keeping track of finances, managing medication, doing laundry, and housekeeping.

The integration of home technologies such as sensors, apps, and even robots represents an opportunity to support independent living among the older population. In addition, these home technologies can impact home care, not only by making it more efficient in terms of costs and timing of health-related treatment, but also by offering solutions that encourage independent living and enhanced quality of life for aging adults. For solutions to be effective, ongoing assessment of an individual's level of function and need for assistance is required. Early on, small home modifications may suffice; however, over time, more interventions may be needed, including user-friendly assistive technologies. Changes in health and function can be a factor when an older adult and his or her family decide that institutionalized care is required, and it may be possible to defer that decision through the use of appropriate and effective assistive technologies. An evolving suite of technologies will be required to maximize independence throughout the continuum of care.

Many basic devices have been developed to better support the key activities of independent living, but many assistive technologies are in their infancy and/or not widely available. What is available may require further evaluation before being implemented more widely or may benefit from research into its effectiveness and value. Understanding how older adults use technology and the best methods for teaching them how to utilize the technology to meet their needs is key to supporting adoption and avoiding user frustration. Cost and convenience also play a role in adoption of technology for older adults, since many older adults live on fixed incomes. New assistive technology research should fill a need that is not already being met for older adults; otherwise, the technology will not be considered useful and may not be adopted.

When evaluating the needs of assistive technology for ADLs and IADLs, three focus areas were identified that were deemed key to independent living as well as potentially benefitting from technology:

- **Hygiene**: bathing, oral care, and skin care, including wound prevention and care
- **Nutrition**: meal preparation, shopping, and eating
- **Medication**: management and adherence

While the capability to walk and transfer is considered to be an activity of daily living, the importance of this ability to all other activities has prompted the Task Force to consider the topic in an independent section of the report (Section V, Personal Mobility).

[6] https://aspe.hhs.gov/basic-report/measuring-activities-daily-living-comparisons-across-national-surveys

Hygiene

The following ***functional needs*** are related to maintaining proper hygiene and can be enhanced through new technology. Recommended R&D topics are listed for each. This structure of listing functional needs for each focus area, followed by a bulleted list of recommended R&D topics to fulfill that need, continues throughout the report.

Enable Safe and Regular Bathing and Showering to Maintain Healthy Skin. The bathroom is one of the most dangerous places for older adults.[7] Bathing and showering can be a challenge for people whose mobility and flexibility is limited. This challenge can result in slips and falls that can cause serious, life-altering injury or death. Being able to bathe or shower regularly and safely is essential to maintaining health and dignity at any age and is especially important for older adults who wish to live independently. Recommendations for R&D to enable safe and regular bathing and showering and to minimize pathogen transfer include the following:

- Optimize and test smart showers that can sense the presence of an individual and accordingly adjust the timing, water flow, and/or temperature to meet the person's specific needs. Showers could include sensors that time water flow and water direction, regulate water temperature, and control soap dispensing.
- Advance technology that supports self-care monitoring and provides alerts to caregivers that intervention may be needed. This technology could provide a range of patient data that can be accessed by caregivers and/or primary care professionals via a wireless application system, including: time-stamped data, location, water usage, water temperature, and unique physical and behavioral changes.
- Assess the impact of home technology and the resulting changes in the hygiene-related aspects of care delivery systems on their effectiveness and value.
- Determine the actual incidence of disease or infection due to bacterial transfer from handheld technology. This information may support the development of effective messaging and behavioral modification strategies to encourage proactive behavior in terms of hand hygiene.
- Develop robust, cost-effective materials that can reduce bacterial colonization on items that are frequently handled (e.g., mobile technology, TV remotes).

Maintain Oral Health. The ability to care for and keep one's own teeth is important in maintaining quality of life. Oral health is related to taste and smell, which are also factors in healthy eating. Avoiding dentures also reduces out-of-pocket and insurance charges. The current approach to oral health for older adults involves going to the dentist regularly to promote prevention and obtain periodic professional assessments and care. Because there is more variability in oral health in older adults than in younger groups, monitoring and support for prevention in oral health at home is critical.

- Design oral health devices for use by older adults that can account for low visual acuity, poor coordination, poor hearing, and, in some cases, diminished ability to understand instructions.
- Expand sensor measurements beyond the amount of time that someone brushes to also include pressure, contact angle, and the tooth surfaces that are brushed.

[7] https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6022a1.htm?s_cid=mm6022a1_w

- Develop systems to support personalized dental regimens based on in-home assessment of the mouth's biological conditions (e.g., salivary biomarkers). Such regimens are expected to improve individual dental health and reduce the cost of future interventions. Communication of data to users and others identified by the user could also provide an early indication of changes in an individual's overall health.
- Advance systems of reminders, alerts, and real-time feedback to patients on their at-home oral care. These would replace and improve upon current patient education materials. These active, personalized dental care systems may include smart toothbrushes or embedded devices in mirrors. Additional research on the use and effectiveness of these tools is warranted.

***Prevent, Monitor, and Properly Care for Wounds*.** Wounds may result from many chronic illnesses, such as diabetes and peripheral vascular disease, or may result from pressure-induced skin degeneration in individuals with limited mobility (bedsores). Wound monitoring and care is a complex and intricate process that may be difficult for some older adults to manage. Success at personalized wound care requires both cognitive and physical ability. Current methods treat wounds after they occur, which misses an opportunity for prevention or monitoring for faster healing. Advances in smart technology, such as sensors that can detect bacteria, may prevent nursing home admissions or hospitalizations and thereby dramatically reduce treatment costs.

- Evaluate and advance the use of smart textiles to augment natural sensation in individuals with neuropathy. For example, prototype optical-fiber-based smart socks have been demonstrated that can measure plantar pressure and temperature in shoes.[8] Adoption of such technology could reduce the occurrence of diabetic foot ulcers and other conditions that may progress and result in amputation.
- Enhance automated systems for skin pressure variation in order to prevent pressure ulcers due to continued time in a wheelchair or bed. Current recommendations for manual shifting of weight require an individual to have adequate upper body strength and be aware of the need to shift his or her weight, both of which can be reduced in aging individuals.
- Assess and advance technologies that automatically monitor existing wounds and infections, such as "smart bandages" that detect movement, deliver drugs, monitor healing, detect infection, and transmit results directly to the physician.[9]
- Evaluate and advance current systems that help clinicians detect wound infections at the bedside or in the doctor's office. These systems would allow clinicians to prescribe appropriate therapies sooner, lower healthcare costs, and improve patient care outcomes. For example, inexpensive, disposable electrochemical sensors that can immediately reveal or correctly identify the type of bacteria within a specific location[10] and simple image analysis[11] can both be effective at monitoring wounds.
- Design an integrated system of implantable biomaterials that will administer biochemical, electrical, or mechanical factors conducive to specific cell types to promote healing, while monitoring bacterial growth and communicating data back to an app or caregiver.

[8] https://www.ncbi.nlm.nih.gov/pubmed/28513212

[9] https://www.ncbi.nlm.nih.gov/pubmed/26821765

[10] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4853203/

[11] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5062001/

Nutrition

Meet Daily Nutritional Requirements. Meeting daily nutritional requirements is vital for the maintenance of physical and mental health as well as for emotional well-being. Ensuring healthy eating in older adults, who may have challenges in obtaining and preparing food, is left to the individual or caregivers and may become a factor in the loss of independence.

- Develop improved geolocation and price comparison services to empower consumers to pursue a healthier and more nutritious lifestyle. Price and location of food have been cited by older adults as barriers to adopting a healthier diet.[12]
- Validate virtual assistants/coaching services related to food preparation to ensure that user needs are being met and that these services are having a measurable, positive outcome on behavior.
- Evaluate automated food preparation systems, such as robotic systems,[13] and continue R&D to advance these systems as warranted.
- Enhance understanding of how older adults are employing existing technologies, such as on-demand meal/grocery delivery and online-diet coaches, to meet daily nutritional demands as well as any factors that may impede their adoption.

Feed One's Self. Beyond acquiring and preparing food, individuals must be able to feed themselves to maintain independence.

- Evaluate robotic feeding systems[14] that are designed to allow individuals to feed themselves and continue to advance the technologies to improve their effectiveness.
- Develop educational and outreach programs to support the acceptance of these robotic tools and overcome preexisting stigma and/or negative perceptions about the use of robotics.
- Determine ways in which these assistive systems may be made more cost effective; for example, by first deploying them in communal living environments rather than in single-family homes.

Medication

Maintain Therapeutic Medication Levels. Efficacy and safety of prescription and over-the-counter medication relies on an individual maintaining proper dosing and avoiding negative drug interactions. For older adults, taking multiple, duplicative, or unnecessary medications as well as taking certain drugs can increase the risk for serious adverse reactions that could lead to falls or cognitive impairment, limiting functional independence and requiring additional health resources. Advancements in technologies should be considered during drug development as part of patient-centric approaches to developing products that can better address the specific needs of older adults who may face challenges with vision, dexterity, and cognition.

- Develop sensors that integrate monitoring of real-time physiological and pharmacological factors, such as blood glucose, heart rate, and drug levels, with real-time monitoring of medication adherence and physical activity. Such sensors could move the field toward a "precision adherence" model that guides highly personalized and tailored therapeutic approaches, including real-time drug dosing.

[12] https://www.aarp.org/content/dam/aarp/aarp_foundation/2016-pdfs/Healthy_Living_Diet_Perceptions.pdf

[13] For example, see http://uhra.herts.ac.uk/bitstream/handle/2299/17234/07322264.pdf

[14] For example, see https://www.resna.org/sites/default/files/conference/2016/emerging_technology/chung.html

- Design integrated sensor approaches to help avoid dangerous drug toxicities or interactions that may result from over medicating or improperly mixing medications.
- Improve adherence monitoring by leveraging tools like wireless medication pill organizers, electronic packaging, and digital pills. Passive sensors offer novel opportunities for real-time intervention and adherence feedback, delivered alone or in combination with cellphone-based technologies.
- Develop technology to help people with impaired vision identify their medications, read medication labels and inserts, and verify that they are accurately taking their medications.
- Advance mobile phone-based adherence interventions beyond daily reminders through more sophisticated comparisons of text message content and timing. Interventions should also diversify beyond text messages to better incorporate a broad set of existing and emerging wireless and connected health technologies. These tools provide exceptional capacities for tailoring adherence interventions in response to personal preferences and observed behaviors through adaptive programming or artificial intelligence. Additionally, such technologies could assist older adults with timing their medications when foods or other drugs may positively or negatively affect their effectiveness and safety.
- Develop context-aware technology that can detect and understand the relationships between users and their environments and activities (e.g., surroundings, work and home routines, exercise habits) to support precision regimens. Advances in analytics may allow technology to actively adapt to a user's needs.
- Develop automated medication reconciliation systems and clinical decision support systems that allow clinicians to understand a person's full medication use to reduce the simultaneous use of multiple medications and unintentional duplication of therapy, and ultimately to adopt simplified prescription regimens that are more effective, safer, and easier for users to follow.
- Identify the most effective ways to report information on adherence back to providers by providing data that is accessible, actionable, and delivered at the right time to the appropriate members of healthcare teams, including pharmacy staff.
- Integrate mobile adherence data with electronic health records to foster better individual adherence outcomes as well as facilitate the testing of large-scale system interventions and health information exchanges. Such data integration could generate evidence to improve medication management across populations. Whether at a large or a small scale, proven and promising adherence interventions with mobile and connected health technologies should be moved into routine care settings and tested through rigorous implementation science.

III. Cognition

Cognitive changes are common during aging, with increasing prevalence at older ages and spanning in severity and impact from the ubiquitous "senior moment" to advanced dementia. Cognitive decline interferes with a person's ability to manage chronic health conditions that are known risk factors for dementia, including high blood pressure, high blood glucose levels, and various forms of heart disease. Therefore, technologies that help to monitor these conditions and coordinate care will increase the ability of individuals to live independently. (Technologies for coordinating patient care are discussed in Section VII, Access to Healthcare.)

In 2017, there were 50 million cases of dementia across the globe. In the same year, the United States had approximately 6 million people over the age of 65 with clinical Alzheimer's disease (AD) or mild cognitive impairment (MCI) due to AD, along with approximately 47 million people with biological signs of AD (amyloidosis, neurodegeneration, or both). By 2060, the number of people in the United States with clinical AD or MCI due to AD is predicted to grow to 15 million.[15] As a result of the prevalence of AD and other dementias, along with the estimated increase to 152 million cases worldwide by 2050, the World Health Organization declared dementia to be a public health priority.[16] Given the aging of the U.S. population, innovative models of care are needed to meet the demand for high-quality, person-centered care.

Management of AD is expensive, both to families and society. Estimates from 2010 suggest that care for people with AD in the United States cost up to $215 billion dollars that year, and that most of this cost was borne by family or informal caregivers.[17] For example, care-related costs for a person with dementia are predicted to be $184,500 higher over a lifetime (86% incurred by families) than for an individual without dementia.[18]

Existing and future technologies offer both challenges and opportunities in the everyday assistance of cognition for older adults. Incorporating the perspective and preferences of older adults, including differences that may exist based on gender, ethnicity, and socioeconomic background, is important in intervention planning that involves technology. The manner in which older adults relate to technology as a potential support for everyday life—both present and future—will determine the role that these technologies play.

Technology advances may help remotely monitor older adults for changes in cognition, for changes in their ability to maintain independence in daily activities, and for safety in their daily lives. Three focus areas have been identified for mitigating changes in cognition: cognitive monitoring, cognitive training, and financial security. As in the prior section, each focus area includes a set of key functional needs followed by a list of recommended R&D topics.

Cognitive Monitoring

***Regularly Assess Reasoning, Memory, and Communication Abilities*.** Because baseline cognitive ability varies significantly from person to person, and assessments can often be influenced by a person's quality and duration of education as well as many other factors, determining what is normal

[15] https://www.ncbi.nlm.nih.gov/pubmed/29233480

[16] https://www.who.int/en/news-room/fact-sheets/detail/dementia

[17] https://www.ncbi.nlm.nih.gov/pubmed/23902508

[18] https://www.ncbi.nlm.nih.gov/pubmed/28815557

for an individual is not straightforward. Many changes in cognition are recognized only after the fact, when more severe impairment is identified, and subsequent efforts to prevent decline may be too late. Technology can help eliminate many of the inherent issues with current standard assessments by allowing real-time, frequent, unobtrusive, objective measures that allow detection of more subtle, pre-symptomatic changes. Recommendations for R&D to address the need to regularly assess reasoning, memory, and communication abilities include the following:

- Determine the feasibility, validity, reliability, and health/social impacts of technological approaches for cognitive assessment. Evaluations of technologies should be based on their use by diverse, real-world populations. Research should particularly address older adults living within highly disadvantaged contexts or from low-resource groups.
- Obtain data related to the cost effectiveness of these technologies as well as which groups are most likely to benefit from them.
- Understand how remote technologies can be practically integrated into health system operations and healthcare delivery, as well as what format improves clinicians' willingness and comfort using these technologies.
- Assess whether the perceived benefits of monitoring technologies outweigh potential concerns regarding privacy, autonomy, and consent; determine who is permitted access to and use of the information gathered, especially for continuous monitoring; and clarify who is responsible for any action based on the information gathered.

Cognitive Training

***Enhance Baseline Ability*.** There is considerable interest in identifying methods that will improve cognition to help stave off decline. Thus far, most cognitive training technology available to the public has been developed for the direct-to-consumer market. Although there has been empirical support for modest improvements to narrowly-defined aspects of cognition following interventions in research settings, the efficacy of most products on the market has not been supported by independent research.

- Determine whether cognitive training, and which type of cognitive training, is an effective method to improve or delay age-related cognitive decline and/or onset of pathological cognitive impairment. Determine which domains of functioning are affected and for how long. This research would clarify the potential benefits as considered by evidence-based reviews.[19, 20]
- Promote development of novel and engaging cognitive training applications and rigorously assess evidence of long-term cognitive improvements that impact daily functioning. This research may be facilitated through the development and use of interventions that target a specific neural system/functional domain, making it easier to assess change. Augmenting existing technology platforms that are already accepted among older adults may lead to improved adherence. Research programs with more training and longer follow-up timeframes are also needed.
- Foster and improve evidence and research on cognitive training programs wherein training related to a particular cognitive domain, such as memory or information processing/speed, is readily generalizable to real-world situations and needs. Encourage research that addresses actual needs in terms of cognitive training, ideally tailored to individual needs and situations.

[19] https://effectivehealthcare.ahrq.gov/topics/cognitive-decline/research-2017

[20] https://www.nap.edu/catalog/21693/cognitive-aging-progress-in-understanding-and-opportunities-for-action

Provide Cognitive Rehabilitation. When individuals begin to experience age-related cognitive decline, technology may be able to mitigate the changes. Remote interventions may provide advantages over traditional in-person visits, which may not be feasible in certain circumstances. With the increased use of mobile devices, wearable sensors, and novel human-computer interfaces, new possibilities are emerging to expand the cognitive tele-rehabilitation paradigm. In the past, cognitive rehabilitation would have required office visits with unmonitored assignments between visits.

- Determine the efficacy of available training for individuals with impaired cognition. Current evidence remains limited because studies have often been underpowered, short in duration, or lacking a standard, baseline assessment.
- Explore design opportunities and considerations when applying emergent pervasive computing technologies to cognitive tele-rehabilitation.
- Develop an iterative process for use with rehabilitation clinicians that can take into account a patient's changing recovery trajectory.
- Develop and validate baseline measures and tools through which the effectiveness of interventions can be assessed.

Financial Security

Enable Independent Financial Management and Prevent Exploitation. It is important to enhance or extend independent financial management by older adults, including those experiencing early cognitive changes. Many of the financial self-assessment tools on the market, ranging from books and websites to financial planners and downloadable apps, are geared toward a younger population. Scant work has been geared toward elderly populations and their specific needs for financial assessment. The increasing sophistication, rapid changes, and frequent use of technological systems create an environment in which older adults may be taken advantage of.

- Develop or adapt existing technological tools to assist in simplifying the financial decision-making process for older adults as they address the burdens of managing expenses and life-changing choices.
- Examine the impact of the increased availability of financial health measures through technology or the internet and how these might affect decision making after learning one's score, including how well a product works for a targeted population and for specific purposes.
- Utilize technology to ensure that all adults have exposure to financial literacy training as part of their financial interactions in order to provide them with a more solid foundation on which to base decisions and help them to plan for the future.
- Adapt interfaces for online banking and automated teller machines to support older adults.
- Regularly and publicly evaluate existing financial monitoring techniques for efficacy, feasibility, and acceptability, including methods employing: third-party, read-only access to accounts; fraud detection and notification; aggregated account monitoring for indicators of financial exploitation; and anomalous transaction alerts.
- Assess the efficacy of both existing and developing technologies for identification, such as wearables, biometrics, and geolocation, to prevent elder financial exploitation.

***Identify Older Adults with Reduced Financial Capacity*.** It is important to effectively and efficiently identify individuals who may be at greatest risk of financial exploitation, with an appropriate plan for responding to these risks that match with a person's individual goals.

- Convert existing tools for assessing financial capacity into electronic formats to allow wider use. For example, the Financial Capacity Instrument is a standardized psychometric instrument designed to assess financial activities and abilities relevant to community-dwelling adults.[21] However, it requires training to administer the instrument and interpret the results. Technology might reduce the need for training and make it more widely available.
- Advance understanding of the relationships between existing measurements of financial functioning and assessments of other types of functioning, such as computer use, driving, cell phone use, and mobility, to determine how non-financial deficits may predict declines in financial capacity.
- Improve prediction of risk on an individual basis to increase the benefit from interventions regarding finances.

IV. Communication and Social Connectivity

Communication between older members of society involves three separate factors: the physiological ability to communicate (hear, speak, see, and touch); the ability to understand one another (language and cultural differences); and the technological ability to communicate across distances for social and professional interactions. This third aspect includes relatively close-proximity communication (face-to-face) that can be addressed with hearing devices, as well as long-distance communication that can be enhanced by information and communication technologies (e.g., internet applications and social media). All three factors are integral to maintaining social connectivity among the aging population. (An additional area of communication that impacts the health and independence of the aging population is telehealth, discussed in Section VII, Access to Healthcare.)

Hearing

Communication challenges for the aging population may be due to hearing loss resulting from an injury or illness or simply as a result of the aging process. Advances in hearing assistance technologies can dramatically improve the quality of life experienced by older adults. However, much needs to be done to make these technologies more accessible through simplified operation, improved performance, and reduced cost. What is promising, however, is that the baby boom generation is comfortable with technological advances and is much more inclined to embrace their benefits.

***Provide Effective Hearing Assistance*.** The ability to hear is key to the ability to communicate for most people. Technology can provide assistance when natural hearing has deteriorated. Devices are needed to help hearing impaired individuals understand speech in noisy environments. Current hearing-assistive devices are generally designed for one-on-one conversations at close distances and are less effective outside of these specifications. Recommendations for R&D to address the need for effective hearing assistance include the following:

- Develop systems that include the ability to share audio channels between hearing aids, smartphones, remote microphones, and other consumer electronic devices through a non-proprietary, wireless link with the short latency needed to understand speech.

[21] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4712121/

- Develop open protocols for wireless communication of the audio input of hearing aids with other systems, including smartphones, microphones, and other wearable electronics. These protocols are needed to expand the ability of hearing aid users to utilize other common technologies.
- Advance the technology used to collect and process sound, as well as the computational power of assistive devices, to improve performance in noisy environments, noise-source identification and cancellation, speech localization and recognition, and auditory (or visual closed-caption) reconstruction.
- Identify and advance necessary technologies to enhance the computational power of hearing assistive systems so they could take advantage of existing or future smart systems to improve their functionality. More computational power would also increase the ability for *hearables* to interface with other smart systems that could offer enhanced features, such as reminders of forgotten names via face recognition, health alerts synced to fitness monitors and smart watches, and navigational information from Global Positioning System (GPS) applications.
- Develop appropriate policies, requirements, and technologies for the sale of over-the-counter hearing aids.[22]

Expand Acceptance and Implementation of Hearing Assistance. The willingness of individuals to accept their need for assistance with hearing, and even more importantly their willingness to obtain a professional assessment of their hearing, is the first step to obtaining an assistive device.

- Develop the ability to check hearing levels using automated hearing tests online or through common smart devices. This advancement will make initial assessment of hearing loss inexpensive, discrete, and convenient and should increase the rate of assessment among individuals.
- Develop enhanced hearing loss simulation programs that allow hearing-impaired individuals to replicate their hearing loss to demonstrate to family members and friends the impact hearing loss has on the ability to understand what is said. Programs should permit the individuals to input their speech into the program and modify the listening situation to simulate restaurant noise, small and large groups, etc., to demonstrate how a specific hearing loss degrades speech clarity in various communication environments.
- Develop standard, open remote protocols that can be used to adjust and tune hearing assistive devices. Currently, hearing aid adjustments are proprietary to each manufacturer. This requirement limits choices for individuals seeking service or tuning of their hearing aids, especially in rural areas. Standard and open protocols that read and set fitting and operational parameters for hearing aids would allow hearing professionals to access the settings of an aid purchased from another vendor, enable telehealth applications to provide professional assistance to users in remote areas, and allow users to self-fit and self-adjust their devices.
- Conduct research into policies and standards in order to make hearing devices more easily and affordably accessible, especially in areas underserved by audiologists.

[22] https://www.fda.gov/medicaldevices/productsandmedicalprocedures/homehealthandconsumer/consumerproducts/hearingaids/default.htm

Communication with Diverse Communities

Translate Conversations between Physicians and Patients. According to the 2016 American Community Survey (ACS), 21% of U.S. residents speak a language other than English at home, including many people born in the United States and 15% of those over the age of 65.[23] It can be difficult for patients to understand medical jargon, and this difficulty is exacerbated if they do not share a first language with their healthcare providers.

There are multiple benefits that would come from developing technologies to assist in translating conversations between physicians and patients. These were categorized by one technology developer as: reduced costs; reduced administrative and staff burden; increased quality and accuracy; mobility; and clinical applications—capturing the spirit and intent of the communication by recording the actual communication and the interpreted/translated version.[24] These same benefits could be realized for aging Americans, their caregivers, and family members. Additionally, verbal or non-verbal communication between providers and patients from diverse communities can lead to improved rapport and empathy.

- Continue to improve and expand automated translation technology. Achieving nearly universal automated translation is technically very challenging because there are between 6,000 and 7,000 languages and dialects, most languages are not written, and every language is context dependent. Advances in artificial intelligence have the potential to enable rapid, reliable, real-time translation of one language into another, including idiomatic language patterns.
- Expand the ability to convert recorded audio (including in videos) into text. This capability has been steadily improving, with the availability of many free software programs. However, more research is needed to expand these abilities across many languages and idiomatic language patterns, including transcribing into the source language and into an alternate language of the listener. Such software could support aging individuals, their families, and healthcare providers by providing them with written documentation of conversations, instructions, and written communications in their primary languages.

Social Communication Technologies

Maintain Social Connections. Social isolation and loneliness among older adults are linked to depressive symptoms, poor cognitive functioning, disrupted sleep, lack of physical activity, and impaired mental health—all of which have implications for increased mortality.[25]

- Promote systematic research demonstrating the effectiveness of interventions, including online social networks, to reduce social isolation and loneliness among seniors, as well as the mechanisms by which the interventions exert effects.
- Develop technological solutions to minimize the risk of predatory social media campaigns.

[23] https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_16_5YR_B16007&prodType=table

[24] http://www.healthcarefinancenews.com/news/5-benefits-healthcare-translation-technology

[25] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4383762/

- Promote collaboration between device manufacturers and the academic community to design products that address the need for social connectedness in older adults, starting with the initial design phase.
- Advance understanding of the technological needs of older adults with disabilities. This understanding is imperative, because disabled older adults are generally less likely to use communication technology.[26]

V. Personal Mobility

Mobility is a key factor in living independently. Mobility generally refers to all movement, including basic ambulation, transferring from a bed to a chair, walking for leisure and the completion of daily tasks, engaging in activities associated with work and play, exercising, driving a car, and using various forms of public transport.[27] Simply put, mobility allows people to get where they want to be, when they want to be there, without impediments, safely and reliably. As documented by the National Household Travel Survey, older adults tend to become less mobile with age.[28]

In order to truly live independently, an individual must have the ability to control his or her movement (basic mobility), avoid slips and falls, and be able to move around the neighborhood and larger community. Each of these requirements has its own challenges and, therefore, distinct sets of technologies that hold promise to address these challenges. The needed technologies can be grouped into three focus areas: assisted movement, rehabilitation, and monitoring and safety. Some of the focus areas have been addressed within an experimental paradigm (e.g., robot navigation) but have not yet been demonstrated in the community. Additional research is needed to fully assess user needs in this area and develop the data analytics and software tools that will make technologies fully successful in helping older adults achieve and maintain independence.

Assisted Movement

Provide Assistance with Navigating the Home and Neighborhood. When individuals experience either physical or cognitive deficits, they are often unable to navigate their homes or local communities without assistance. Assistance may focus on guidance or involve a surrogate system to move around the home and conduct some basic activities, for example, picking up needed items located in another room. Recommendations for R&D to provide assistance with navigation include the following:

- Design robots that are robust enough to require little maintenance or troubleshooting and that have long battery life and are easy to recharge.
- Design accessible drop-off and pick-up stops for assistive mobility robots, including automated vehicles and low-speed shuttles for mixed use within neighborhoods and communities.
- Develop affordable control systems, appropriate sensing, information processing, and decision-making algorithms to allow robots to negotiate the navigation environment of the home, such as dynamic and static obstacles, uneven floors, stairs, varying lighting conditions, and door thresholds.
- Develop smart robotic technologies that not only respond to an individual's needs but also can learn and modify a robot's behavior based upon the owner's requirements and usual habits.

[26] http://www.pewresearch.org/fact-tank/2017/04/07/disabled-americans-are-less-likely-to-use-technology/

[27] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3464831/

[28] https://nhts.ornl.gov/

Mechanically Compensate for Reduced Strength and Mobility. Individuals with reduced musculoskeletal function often require assistance with balance and/or range of motion. Current research on technological solutions, including exoskeletons, is primarily occurring in clinical rehabilitation centers involving individuals with paralysis and their caretakers. Real-world environments often involve everyday tasks that are challenging and have the potential to be unsafe.

- Develop assistive mobility technologies for less supervised environments and tasks, like traversing up or down a street curb, walking on uneven terrain (e.g., ramps, stairs), or walking up to a counter to grab an object.
- Address control, comfort, and safety-related functionalities in wearable mobility systems, such as exoskeletons, and incorporate hybrid features that allow control to transition between the exoskeleton and the user.
- Advance science and engineering focused on employing a brain-computer interface for controlling exoskeletons.
- Develop algorithms for activity recognition and indoor location detection that are suitably reliable and accurate enough for real-world use.

Rehabilitation

Enable In-Home Rehabilitation. Current rehabilitation programs require older adults to go to clinical facilities, which limits who can attend and for how much time they will receive therapy. To minimize cost, maximize access, and maximize the amount of time that can be spent pursuing rehabilitation activities, systems enabling in-home therapy are needed.

- Explore the role of virtual reality and gaming systems for improving functional independence among older adults. There is evidence that virtual reality can be used by older adults at home to improve their gait following a stroke.[29] It has been proposed that virtual reality and gaming systems may enhance physical activity and improve health, but evidence for success is weak.[30] The impact of such systems warrants further research, including into how to use these systems with older adults more effectively.
- Design and develop affordable rehabilitation devices to promote intensive practice of a gait-like movement pattern for older individuals with physical disabilities and chronic conditions.
- Examine the use of smart-home technologies for rehabilitation purposes, including monitoring for improvement or prevention of functional decline.

Monitoring and Safety

Monitor Movement and Activity. Changes in activity are an indication of individual well-being. Measures of movement and activity can indicate both acute and gradual changes in well-being.

- Improve the reliability and usability—including battery life and comfort—of sensor systems and algorithms that focus on either activity- and fall-recognition or indoor location detection in order to support deployment in the real world. Systems need to be more usable so that they can be effectively deployed for extended use to assess possible declines in individuals and enable early interventions.

[29] https://www.ncbi.nlm.nih.gov/pubmed/23614694

[30] https://www.ncbi.nlm.nih.gov/pubmed/24351549

- Promote research efforts and examination of systems to dynamically assess sit-to-stand transfers. Parameters need to be collected to determine normal ranges and cut-off values for time to transfer as well as body movements during the transfer that cannot be reliably recorded manually.
- Develop algorithms that fuse and combine data from multiple movement and activity sensing systems to provide increased accuracy for the assessment of individual well-being. These may include the application of artificial intelligence and should provide useful information to users, healthcare providers, and caregivers, as appropriate.

Prevent Falls. Falls result in significant morbidity and mortality among the aging population, so their prevention is key to maintaining independence. Systems are needed that can train individuals to minimize fall risk and assess those most at risk for falls.

- Develop technology-based strategies, especially for in-home use, for fall prevention training. Older adults can be trained to rapidly adjust their behavior to prevent a fall in experimental settings,[31] but these strategies should be adapted for the home setting.
- Determine the key parameters for assessment of fall risk as they relate to the cognitive aspects of fall prevention, particularly measurement of reaction time as a means to determine an individual's ability to correct a loss of balance and prevent a fall.
- Develop technologies to measure the reaction time of individuals during instances where they lose their balance, must recognize the perturbation, and must correct it before falling.
- Promote the use of larger trials on the use of existing technologies, including accelerometers, to investigate reaction time as a measurement for fall risk, and include both a healthy aging population and those with other progressive conditions that could increase fall risk, such as dementia. These tools have the potential to become standards for measurement of cognitive decline and slowed processing that could be used both to prevent falls and to assist in determining when someone needs a higher level of assistance or care.

VI. Transportation

Movement around and beyond the community is key for individuals to be able to access social, health, and business facilities. As each person is unique, so too is his or her ability to live independently, along with the resultant transportation needs and limits associated with each person's physical and cognitive abilities. Some older adults are completely independent and continue to drive without assistance, while others may be able to drive but require vehicle modifications and/or some advanced technologies to assist them. Other older adults have transitioned away from driving altogether, sometimes due to age-related disabilities, and rely fully on public transportation and a variety of other transportation services. Finally, there are older adults who also rely on services and technologies, not only for transportation, but for basic day-to-day mobility as well.[32]

For the purpose of this document, the broader community area was defined as being greater than one mile from the home. Technologies to support transportation may vary depending on the distance of travel planned. Movement around the broader community can be via private vehicle (driving) or public transportation—the two focus areas for this capability topic. (Similar technologies are also needed to assist with long-distance air and rail travel.)

[31] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5335723/

[32] https://rosap.ntl.bts.gov/view/dot/31320

Driving

Assess Driving Fitness and Help Drivers Maintain their Driving Fitness. As drivers' cognitive and physical abilities change with age, driving skills need to be evaluated. If a driver's physical or cognitive abilities have declined, it is possible to develop systems that could allow that individual to continue to drive independently and safely. Technological systems that can supplement or replace physical or cognitive actions by the driver would extend the ability of individuals to drive following chronic or acute reductions in ability. Current best practice is to use some form of testing (most often vision) at license renewal periods, leaving long periods of unassessed driving skills and different rules in different States. Current adaptations are based on drivers' resources, meaning that those with resources will be better able to extend their driving time. Recommendations for R&D to address driver fitness and help drivers maintain their driving fitness include the following:

- Determine what measurable factors best assess driving fitness in order to develop tools that can support both self-assessment and professional assessment of fitness for driving, including measuring cognitive ability and demand related to human factors and situational awareness.
- Develop tools that can accurately and objectively measure these factors of fitness and provide the results of an assessment to the driver or a professional on whether the individual is likely to be fit to drive or may need assistance.
- Design a real-time link between self-assessment and access to the vehicle, such that individuals who should not be driving without assistive technology will not do so. This link would apply to drivers with a drop in cognitive function as well as those with a reduction in physical fitness (e.g., vision, muscle strength, range of motion).
- Develop assistive technology that can be easily adjusted to account for changes in musculoskeletal factors that affect fitness to drive. Such technology would extend an individual's ability to drive without requiring substantial time or monetary resources to implement new assistive systems as physical abilities change.
- Continue to advance the development of automated vehicles, which will provide broader access to private vehicles for the aging population.
- Continue to enhance advanced safety and driver assistance systems to improve road safety and reduce crash incidence in general. Research is needed to determine the level of inherent fitness that must be demonstrated by individuals even with the availability of these systems.
- Encourage the development of future training systems that allow aging drivers to practice driving with "unexpected" scenarios and thereby develop or reinforce confidence in driving ability. (Lack of confidence can result in a greater chance of driver error due to indecisiveness.)
- Develop systems to allow individuals with mobility impairments to independently access their vehicles and easily store wheelchairs (manual or power) or scooters inside their vehicles, thereby improving their transportation independence.

Public Transportation

Public transportation may involve any combination of personalized and mass transit systems, including taxis, ride sharing, shuttles, buses, ferries, and trains. The availability of each of these systems varies significantly from community to community. This document does not address the general availability of public transportation options, which is a primary user need. It focuses instead on the needs of individuals for assistance with navigation, scheduling, and access, assuming that public transportation is available.

***Assist with Navigation and Scheduling*.** Planned navigation of a route and real-time scheduling information, along with the ability to adapt to changes in traffic or schedule information, are some of the key factors that support ease of use of public transportation. Current technologies that can address these needs are not generally designed to take into account the specific needs of older adults.

- Implement pre-trip wayfinding and navigation systems that connect a planned route (within wearable devices and smart displays) to real-time information that enables independent travel and mobility, including systems that help plan accessible routes, remind users about their planned trips, and provide reminders about what to bring, when to leave, etc., for the entire trip. These technologies are available but are not fully designed or deployed to meet such needs.
- Enhance wayfinding and navigation systems to include electronic orientation aids that can determine an individual's location and plot the most suitable route to the destination. Improvement of dynamic maps and real-time navigation guidance can include a variety of technologies, including robotics, crowdsourcing, advanced path planning, and multi-modal interfaces. While some of these systems were developed specifically for people with visual disabilities, the technology could be refined to meet the needs of the older adult population—in particular those with cognitive deficits.
- Enhance the accuracy of map and infrastructure information for built and pedestrian environments to include information within wayfinding tools, such as the location of stairs and elevators, grade of ramp, and surface roughness. Industry has taken on the challenge of developing accurate maps, but research is needed into how to best bridge the gaps in information obtained from various databases. Common policies are needed regarding the types of infrastructure information that is encoded into these maps (e.g., elevators, curb cuts) so that scalable applications can be developed rather than relying on regional solutions.
- Develop wayfinding and navigation apps that can predict, rather than react to, changes in the environment in order to provide more independence and a sense of security to users. Research is required into how to provide this forward-looking, socially aware guidance. In addition, systems that can notify an individual if he or she is about to make a wrong decision, such as getting on the wrong bus or train, will significantly improve user confidence and independence.
- Develop both robust and accessible interfaces and training methods for smart phone navigation applications. While smartphone apps do exist to support wayfinding on public transportation, many aging individuals m not comfortable using this technology or interfacing with the system. Systems must support individuals with reduced visual acuity or manual dexterity and need to be developed using "universal design" and inclusive information and communication technologies.
- Develop technological tools that can inform family members and caregivers if the rider makes a mistake in navigation. These tools would reduce individual and family stress levels and improve individual safety, especially among individuals with diminished cognitive function.

***Facilitate Access to Public Transportation*.** Once a route is planned, the ability to actually access public transportation without significant delays or extended transit times is important.

- Develop systems that can quickly and safely secure wheelchairs (manual and power), scooters, and other assistive devices (e.g., oxygen cans) within all public transportation systems, ideally without requiring the transfer of the passenger. Encourage systems to be designed to address the needs of individuals with disabilities, including safe securement and restraint systems. These are needed to facilitate the use of public transportation by users of personal mobility systems without adversely affecting system efficiency. Current systems to secure wheelchairs on public buses and

trains often require time that can disrupt the planned schedule for the bus or train. In addition, charging stations for powered wheelchairs or scooters that are integrated into transit vehicles would greatly expand the distance that could be traveled or the time that can be spent away from a home base.

- Implement architectural design standards that meaningfully consider how persons using assistive mobility devices navigate through public transportation stations.
- Enhance wayfinding and navigation apps to access real-time updates on public transportation infrastructure, including the status of elevators or vehicle lifts/ramps. Planning for these variations in routes is important to all travelers, including those with disabilities, and for all surface transportation needs. Real-time updates on public transit infrastructure are important to all travelers on all types of trips to all destinations.
- Develop remote or robotic assistance strategies to reduce wait times and maximize the efficiency of staff, such as distance-based control of gates, elevators on request, and moveable robotic ramps/lifts for train access at stations.
- Develop shared neighborhood automated vehicle networks that can provide access to personalized transportation for all individuals, at all times, and to all destinations. Smaller vehicles may also prove to be a key strategy in addressing first-last mile challenges. Such vehicles would need to be usable without a driver's license and accessible by individuals with wheelchairs or scooters in order to be usable by the broad community as a connection to public transportation. Novel vehicle designs and technology developments are necessary to meet the expanded needs of the aging population.
- Develop technology and policies, including pertaining to privacy issues, to support machine-readable personal profiles for travel support and human services in transportation, as well as to identify the appropriate services that meet the user's needs. For example, providing data to transit companies regarding the ability and needs of an individual (e.g., type of personal mobility system, ability to transfer, and description of assistance needed) would allow appropriate assistive technologies or staff support to be available at the appointed time. Such personalization will reduce wasted time, improve the efficiency of scheduling, and positively impact quality of life.

VII. Access to Healthcare

Access to effective healthcare plays a critical role in helping older adults stay active and independent as they age. Currently many older adults, the majority of whom have multiple chronic conditions, receive suboptimal, fragmented, uncoordinated and, at times, contradictory or harmful care from multiple providers in multiple care settings.

Many different individuals have important roles to play with respect to the application of activities and strategies that support the maintenance of function and independence with age. Participants in this care system include: patients/clients; their families, caregivers, and communities; clinicians; social services and support systems; and community services. Alignment and coordination among these participants through technology can increase the effectiveness and efficiency of these services. In a digital healthcare system, telehealth and electronic care (eCare) planning—the focus areas discussed below—can enable older adults to maintain their independence by increasing access to effective care, coordinating this care, providing support for prevention and chronic disease management, and helping to reduce the stress on older adults, their caregivers, and clinicians.

Telehealth

Telehealth is defined as a collection of means or methods for delivering and enhancing healthcare, public health, and health education delivery and support using telecommunications technologies, regardless of the capabilities or locations of care recipients.[33] Synchronous telehealth (occurring in real time) or asynchronous telehealth may include: (1) clinical video telehealth (two-way, real-time, synchronous interactions between patients, caregivers, or providers using audiovisual telecommunications technology); (2) secure messaging in the collection and transmission of health information to monitor or manage chronic conditions; and (3) care management using telehealth, such as targeted text messages or apps that help patients with reminders to adhere to specific care regimens.[34] Telehealth can deliver services to patients feasibly, safely, and in a way in which both patients and healthcare workers are satisfied with those services, and is already a priority of the Trump Administration to expand access to care for Veterans.[35]

***Improve Healthcare Access and Quality*.** To access comprehensive and appropriate healthcare, it is important that older adults can receive primary care, specialty care, and community services regardless of their physical mobility or location. This need includes providing access to care for rural, underserved, and at-risk individuals and communities, including Veterans. In addition, older adults who cannot easily travel need to be able to communicate with their healthcare providers. The use of telehealth can improve outcomes such as mortality, quality of life, and resource utilization for several chronic conditions, including cardiovascular and respiratory disease. Recommendations for R&D to improve healthcare access include the following:

- Develop, implement, and evaluate scalable and sustainable telehealth programs.
- Develop innovative telehealth technologies that incorporate the use of smartphones, sensor technology, and faster internet to expand the range and functionality of telehealth services.
- Evaluate the impact of different telehealth applications and models of delivery on patients, families, and clinical teams, including: outcomes related to time, costs, and healthcare utilization; the quality of communication and care; and health outcomes.
- Conduct rigorous studies to determine what types of telehealth are most effective in different settings and for what conditions, and how and when telehealth can be incorporated into provider workflow and the lives of patients in ways that promote quality of life and improved health outcomes.

***Promote Smoother Care Transitions*.** The use of telehealth makes it possible to monitor older adults when making transitions between care settings, such as going home from the hospital. Without such monitoring, many older adults are at risk of being readmitted. Telehealth can be used to identify critical issues, including changes in mental status, weight, or blood pressure, thereby facilitating intervention and treatment to prevent hospital readmission. Many older adults are transferred to nursing homes for heightened monitoring to ensure their safety. Telehealth potentially offers an alternative, so that they can safely remain in their homes and communities.

[33] https://www.cchpca.org/about/about-telehealth

[34] https://effectivehealthcare.ahrq.gov/sites/default/files/pdf/telehealth_technical-brief.pdf

[35] https://www.whitehouse.gov/articles/president-trump-secretary-shulkin-announce-veteran-telehealth-initiatives/

- Create and evaluate different payment models to promote reimbursement for innovations in telehealth to increase its adoption, efficacy, scalability, reach, and efficacy.
- Advance interoperability standards and information technology (IT) infrastructure to integrate telehealth services with other digital sources of health information technologies, including electronic health record systems, as an integral part of the health data/information sharing/communications health IT infrastructure.

Provide Self-Management Support. Telehealth can provide effective self-management support[36]—assisting people with chronic conditions to manage their health, including helping them to become more informed about their conditions and assume a more active role in their treatment. Telehealth also provides new ways for patients to participate in their own healthcare by helping them record, measure, monitor, and manage their conditions, and remotely share information, communicate, and collaborate with providers.

- Develop user-friendly, self-management support applications that enable patients to focus on priorities and achieve goals of care.
- Integrate self-management support applications with other technologies that enhance chronic disease management, including those for remote patient monitoring and medication adherence.
- Evaluate the impact of different approaches to self-management support on patients, families, and clinical teams, including: outcomes related to time, costs, and healthcare utilization; the quality of communication and care; and health outcomes.

eCare Planning

Information technology is an important component of care planning that supports care coordination, communication, and collaboration among members of the healthcare team—older adults, families, and providers—to address the full spectrum of a patient's needs across all settings and over time. Care plans provide support to older adults and their caregivers related to accessing information and community resources as well as making connections to formal and informal support services.[37] eCare plans could improve and enhance care planning activities and communication, leading to better outcomes and fewer adverse events. Well-designed eCare plans support patient-centered and coordinated care for older adults. They are developed in conjunction with patients and families, are based on the patient's goals and preferences, and optimize autonomy and well-being. Additionally, eCare plans are individualized, are based on comprehensive assessments, are dynamic, and integrate information about multiple factors, including health needs, family and social history, home environment, values, goals, and preferences.

Improve Coordination of Care. Older adults with multiple chronic conditions and complex health needs require support from a variety of providers and services in order to optimize their health and functional status and to prevent or slow decline. However, in the absence of overall care coordination, these services may be lacking, redundant, ineffective, or potentially harmful. In addition, resulting health outcomes may be less than ideal, while costs escalate. Therefore, there is a need to implement robust care coordination across settings and disciplines to deliver care that is integrated and truly patient-centered.

[36] https://www.ncbi.nlm.nih.gov/books/NBK379320/

[37] https://pcmh.ahrq.gov/page/coordinating-care-adults-complex-care-needs-patient-centered-medical-home-challenges-and-0

- Conduct and publish a systematic review and evaluation of existing eCare planning models to understand successes, lessons learned, and challenges.
- Support implementation and evaluation of comprehensive, shared eCare plans using health IT that are aimed at maintaining and improving the functional status of older adults living in the community.

Facilitate Shared Care Planning. As the capabilities of health IT tools increase and a nationwide infrastructure for electronically sharing health information grows, patients and stakeholders across the care continuum are converging around a vision where a single eCare plan can be created, dynamically updated, and utilized in a secure and appropriate fashion by patients, caregivers, and any member of the patient's virtual, interdisciplinary care team.

- Support research on the development, testing, and implementation of health IT solutions to optimize communication and foster continuity of care through eCare plans.
- Encourage plans that are developed by patients in conjunction with their primary care providers (who serve a key role in coordinating and integrating care across settings) and that are appropriate for community-dwelling older adults. Such plans will enhance providers' capacity to deliver care aligned with a person's goals and preferences.
- Develop tools that optimize communication and foster continuity of care through eCare plans as older adult's transition between settings, including primary care, specialty care, acute care, post-acute care, and home care.
- Encourage the development and adoption of health IT certification standards and platforms for the accessibility and exchangeability of eCare plans. Emerging technologies for application programming interfaces for remote-monitoring devices may help accelerate implementation.

Proactively Plan Care for Complex, High-Risk Patients. Care planning promotes a focus on the patient, improves outcomes, and reduces the costs of care. Ideally, an eCare plan should ensure easy access by patients, their families, and providers alike, using a standard shared care plan format. Care coordinators (or other appropriate personnel) conduct assessments and work with the patient to identify goals, preferences, gaps in care, unmet behavioral health needs, and other social or community needs, such as safe housing, caregiver support, access to and availability of healthy foods, and transportation. Care plans must be systematically re-evaluated and adjusted to assure patients' needs are being met, especially as their needs or circumstances change or progress.

- Support research that identifies social and other contextual and human factors that influence design along with end-users' acceptance, use of, and adoption of eCare plans among care teams for complex, high-risk patients.
- Partner with diverse stakeholders across the health and social care system, including clinical leaders, professional groups, and workforce educators, to better prepare members of the health and social care system to adopt team-based models of care and spearhead adoption of IT-enabled shared care planning tools for complex, high-need patients.

VIII. Cross-Cutting Themes

This section contains cross-cutting needs and challenges identified during the consideration of the six functional capabilities discussed above. Not every need or challenge applies to every capability; rather, these are needs that may be associated with a number of possible technology solutions that are not necessarily specific to individual R&D recommendations. Some represent opportunities for leaps in innovation, and thus may be R&D priorities in their own right. Others may just represent technology issues that should be considered during other efforts. Although some sections are more detailed than others, the level of detail is not intended to convey relative importance. *Note that many of the issues highlighted in this section, notably those related to health IT, open data, connectivity, and cybersecurity, are Trump Administration priorities*.[38,39,40]

System Needs

Many of the priorities identified will rely on traditional system implementation requirements, such as communication and network infrastructure as well as GPS connectivity. These systems also include general-purpose platforms used in technology implementation, such as computers, tablets, and mobile phones. Some research needs might also include "custom" infrastructure, such as the instrumentation of a physical location (e.g., a "Smart Home") and technology to support connected devices (e.g., the Internet of Things, or IoT).

Many focus areas require systems to transmit and exchange information, varying by application, which generally include the following design parameters:

- Timeliness of information needed.
- Inclusion of alarms/notifications (high importance, low bandwidth).
- Need to transmit data.
- Need to "store and forward" (acquire and store locally, transmit when needed).
- Ability to implement "live interactive devices" (video over phone or internet).
- Maintenance of data quality/integrity.
- Management of data volumes ranging from low data rates (e.g., wearables, transactional) to high data rates (e.g., video, telehealth).
- Remote control (for use in closed loop applications or to remotely set parameters).

The following are additional challenges and needs for these IT systems:

- A need to improve day-to-day system dependability, including availability, reliability, maintainability, and maintenance support.
- The lack of system availability at various times or locations due to cellular telephone coverage, GPS signal visibility, power outages, etc. Inconsistent broadband coverage in existing urban buildings and remote areas often prevents universal rollout of these technologies.

[38] https://www.performance.gov/PMA/Presidents_Management_Agenda.pdf

[39] https://www.whitehouse.gov/presidential-actions/presidential-executive-order-streamlining-expediting-requests-locate-broadband-facilities-rural-america/

[40] https://www.whitehouse.gov/presidential-actions/presidential-executive-order-strengthening-cybersecurity-federal-networks-critical-infrastructure/

- System resiliency in emergency or disaster situations when power or services are significantly impacted. Offering alternate functionality or leveraging alternative infrastructure or resources can ameliorate this risk.
- Improved cybersecurity considerations for connected devices.
- Additional wireless spectrum for IoT-connected devices.
- Support for use in smart homes and the broader environment. Smart home technology is still relatively immature, but improvements in system integration, sensor deployment, and data algorithms should enhance the ability of connected environments to address issues such as disability prediction and health-related quality of life (e.g., fall prevention).
- Methods to verify personal identity using technology, such as using wearable technology, biometrics, and geolocation.

User Adoption

Universal design—inherently accessible to people regardless of age or disability—including user centered design, is critical for older adults who may be impacted by a range of factors, including: age-related changes in vision, hearing, or memory; psychosocial factors, such as fatigue, distress, or native or primary languages other than English; and extrinsic factors, such as ambient noise, inadequate lighting, or socioeconomic factors. Development of usability standards and the application of these standards to the design of technology for older adults, even under circumstances of diminished functional capacity, will provide efficient and effective support. Increased research efforts are necessary to determine the optimal accessibility and usability guidelines to support older adults using IT.

Monitoring technology is particularly appealing for enhancing safety, but implementation should be user friendly, interactions must be kept simple, and it must be as invisible as possible. More invasive monitoring, such as video monitoring, must address ethical considerations and the threat to autonomy, and it is recommended that algorithms balance intrusiveness and usefulness.

Specialized training and support can help overcome resistance to adopting new technologies, and combining technology with human interaction provides a more effective educational method compared to videos or phone tutorials alone. Continual learning and adjustment to technological services and updates, however, can also be a barrier to using rapidly changing technology. New technology should be able to leverage existing platforms that older adults are already familiar with in order to ease the transition.

Adoption of technology by older adults is also driven by value and affordability, accessibility, independence, and confidence. Listed below are some factors important to user adoption:

- To maximize the probability that the user will find interacting with the technology useful, the design of the technology should include adequate assessment of user needs, usability analysis and studies, and design methodology that focuses on the appropriate user base. This assessment should include needs-finding through interactions with older adults from a range of socioeconomic backgrounds, caregivers, and clinicians (including geriatricians), recognizing that users will have a range of different attitudes towards and experiences with technology.
- Usability studies have traditionally been qualitative; however, studies should use a quantitative approach and theoretical framework to explain the main determinants of adoption and usage behaviors.

- Use of universal design principles is key, including gathering requirements from the appropriate user groups and the development of a single interface for all functions, rather than separate devices or interfaces.
- "Zero-effort technologies" that require little or no effort from the user will limit the opportunity for user error. Designers and engineers should place the burden on advanced computational techniques to interpret data and be responsive to user needs.
- For wearable sensors, design input should include an assessment of the appropriate sensor size and the need for compatibility with human tissue, especially for systems to be used over an extended period of time. When possible, truly non-invasive solutions should be sought. It must also be recognized that wearing the sensors should be comfortable, and garments should be durable to survive multiple washings.
- When considering user adoption, "user" should also include clinicians and caregivers. The ease of collecting volumes of data can lead to information overload. Users do not necessarily want more data—they want meaningful data. It is important that data be rendered in a meaningful way and that systems do not produce inaccurate results, especially false positives for emergency or predictive situations. (Some of the challenges related to linking raw data to meaningful measures are also discussed in the Data and Algorithms section below.)
- Current Federal and industry standards focus on IT access rather than usability. To ensure accessible and usable services, including interoperable medical devices, universal design principles must be applied to information and communication technologies. Some standards for accessibility for telecommunications services and web content have been outlined in the Telecommunication Act Accessibility Guidelines (TAAG)[41] and the Web Content Accessibility Guidelines (WCAG).[42] The TAAG and WCAG standards have as their express purpose to make information and communication technology and internet websites more accessible to persons with a disability. Therefore, IT designed to meet TAAG or WCAG standards will be more accessible to older adults, including those with disabilities.

Functionality

Several identified R&D recommendations rely on specific methods or technologies, and improvements in the current performance characteristics of these technologies are needed for broader deployment.

- Systems to detect fraudulent bank withdrawal patterns within financial institutions.
- Enhanced algorithms to automatically identify fraudulent emails, include phishing, swindles for Medicare "refunds," and offers of "free" medical supplies.
- Biometric recognition methods for transaction verification.
- Improved systems for accessibility and hands-free use of technology.

[41] https://www.access-board.gov/guidelines-and-standards/communications-and-it/about-the-telecommunications-act-guidelines/section-255-guidelines

[42] https://www.w3.org/WAI/intro/wcag

Privacy and Security

Privacy and security considerations are a key constraint for a majority of the R&D recommendations. Two categories of privacy should be considered: (a) privacy of the individual; and (b) security and privacy of the collected data. Technology solutions should aim to achieve the following goals:

- Balance the need for data with respect for individual privacy.
- Ensure HIPAA-compliant encryption and secure transmission for personal health information.
- Perform cybersecurity risk management and apply a systems-thinking approach to the overall system design and implementation.
- Develop authentication systems for older adults using unobtrusive biometrics or other methods to avoid data tampering.
- Address the security vulnerabilities associated with IoT devices, applications, and smart homes.
- Incorporate cybersecurity considerations into design, such as the NIST Cybersecurity Framework and NIST Cybersecurity for Internet of Things Program.[43]

Data and Algorithms

Many of the recommendations involve collection and analysis of data. Characteristics of the data, the needs associated with the data, and the sensors used to detect, collect, transmit, and store the data have a wide range of requirements associated with their use. Some needs are associated with the sensor hardware itself, including the quality of the acquired data, the analysis of the data to produce meaningful measures, and the infrastructure necessary to support all of the above.

The characteristics of the data collected depend on the intended use. Several types of data streams are possible, each with different needs and requirements. Each may have different priorities, data rates, and quality requirements.

- Event and episode detection and alerting systems, such as acute condition monitoring, generate high-priority, low-bandwidth/data content.
- Continuous monitoring, such as chronic condition monitoring, generates mid- to lower-priority, high-bandwidth content.
- Detection and presence monitoring, such as detecting the opening/closing of a door or sitting on a chair, generates low-priority, low-bandwidth/data content.
- Variable data types, such as individual and repeated values, waveforms (2D), and images (3D), have different needs related to data rates and quality.

While processing some types of data and data streams is straightforward, challenges do exist for several applications where the relationships between the raw data and the outcome measures of interest are not clearly established, including the following:

- Developing robust methods to fuse and process data.
- Validating the results that come out of the data.
- Establishing the usefulness of the outcome measures from the data (i.e., validating outcome measures and demonstrating that the result is clinically meaningful).
- Creating replicable methods.

[43] https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.04162018.pdf

A variety of algorithms, deep learning, and computational techniques, often called artificial intelligence, can be used to process raw data, such as activity recognition, context modeling, location identification, planning, and anomaly detection. A goal is to use data from multiple sensors to understand a situation (e.g., a nighttime bathroom visit) and detect clinically relevant problems based on abnormal behaviors. While there is the potential to use sensor technology to help maintain independence, appropriate validation of sensor-derived data will be necessary. Similarly, traditional pen-and-paper assessments, such as cognitive tests for dementia, should not be simply ported to computerized formats without appropriate validation that the new formats provide at least equivalent results. The following are some other challenges for the use of data:

- Aggregating sensor information of different types—e.g., environmental, cognitive, physical, and physiological—to define new types of information and outcome measures.
- Gathering large enough samples from those with disabilities to have datasets appropriate for the analytics, especially recognizing the complexity of this analysis, in that there is more than one way to perform an activity.
- Differentiating multiple users in instrumented homes.
- Considering the use of low-fidelity activity recognition from sensor data to balance privacy and data collection.
- Ensuring data interoperability so that data from individual collections can be compared.

There are a number of common, required characteristics for analytic methods. Algorithms should be reliable, valid, context aware, and learn with the user. In addition, data streams need to be reliable, low-cost, and more sensitive than current clinical assessments.

Evaluation

Evaluation is a key factor in developing and advancing any health technology. However, evaluation is a complex issue, and assessment of one aspect of a technology—e.g., whether data is transmitted when it is expected—is not the same as whether a project will positively affect health or be adopted in the community. Therefore, multifaceted evaluation of technology targeted to older individuals is required, and evaluation of emerging technologies should include the following steps:

- Comparing developed technologies to the user needs identified through the design process.
- Validating and gauging the reliability of developed technologies to ensure that the system is functioning as intended and in a consistent manner.
- Determining the efficacy and effectiveness of technology in improving health outcomes and assessing whether it can do so through large-scale studies.
- Assessing whether the developed technology meets regulatory standards.

Technology Safety and Performance Needs

Several common challenges have been reported that can impact user safety and system performance, including hardware incompatibilities, unexpected operating system software upgrades, and the need to occasionally reboot a computer. Many of these challenges can be mitigated through the use of open standards, application programming interfaces, technology certifications, and consensus operational guidelines. Other challenges that impact safety and performance include battery life limitations for wearable devices and minimizing the absorption of electromagnetic energy by human tissues. The advancement of energy-harvesting techniques in the future may address some of these challenges.

Safety and security considerations are particularly important for the design and operation of robotic assistive systems to ensure that end users are not harmed by system failures, such as interruptions of power and/or communications.

While user centered design can help to ensure that users' needs are met, designers of technology to meet these research priorities must also consider safety principles and adopt robust product development lifecycle processes to ensure that potential hazards are considered at the start of the development process. Because many technologies will rely on existing infrastructure (e.g., transmitting data, accessing sensors, sending alarms), technology designers should assume that systems will at times operate in a hostile environment and identify and mitigate risks related to their use in such an environment from the start.

Family Caregiver Needs

An essential factor to an individual achieving functional independence is the role of the family caregiver. On a daily basis, family caregivers—oftentimes a spouse, child, or other relative—may be called upon to help manage and execute a diverse set of services, from complex medical care to activities of daily living. A 2016 report by the National Academies of Sciences, Engineering, and Medicine estimates that there are at least 17.7 million individuals caring for someone aged 65 and older with an impairment.[44] By one estimate, the value of such care in 2013 totaled $470 billion.[45] Given that by 2035 there will be 78 million individuals older than 65 (outnumbering those under 18 for the first time),[46] the number of family caregivers and the demands on this group will only increase. Therefore, addressing the needs of family caregivers and the role that technology can have in alleviating their stress are important areas of exploration.

Caregiving, particularly family caregiving, is multidimensional—ranging from basic support for loved ones needing help with meal preparation, transportation, and bill paying, to more complex services, such as medication management and assisted decision making. The desire to provide optimal care to their loved ones is ubiquitous to all family caregivers, regardless of the needs of their care recipients. In doing so, family caregivers may rely on technology to fill gaps in their knowledge of care practices, identify methods to decrease the burdens of caregiving, and learn how to execute more complex care demands.

The 2016 report by the National Academies referenced above also discusses ways in which technology can play a role in the practice of family caregiving and on the health of caregivers. The potential methods by which caregivers can employ technology to help in their roles as caregivers include but are not limited to the following broad areas:

- **Education***:* Consulting internet resources to obtain information on care practices and seek social support.
- **Burden alleviation***:* Participating in technology-based interventions to reduce the emotional and physical burden from caregiving.
- **Remote caregiving***:* Monitoring care recipients remotely via videoconferencing and sensing technologies.

[44] http://www.nationalacademies.org/hmd/Reports/2016/families-caring-for-an-aging-america.aspx

[45] https://www.aarp.org/content/dam/aarp/ppi/2015/valuing-the-invaluable-2015-update-new.pdf

[46] https://www.census.gov/newsroom/press-releases/2018/cb18-41-population-projections.html

In the coming years, the role of technology in helping family caregivers may shift to the growing area of complex care support. A national survey of family caregivers in 2012 highlighted the increasing frequency with which caregivers are providing complex care.[47] The list of complex care tasks rated by family caregivers as difficult included managing medications, wound care, and the use of medical equipment (e.g., dialysis machines). Common needs of caregivers identified in the report include better knowledge about how to properly execute care tasks and better communication with healthcare professionals. Technology, in the form of mobile and web-based applications, online web resources, and sensing/monitoring devices, may help to fill the knowledge gap often experienced by family caregivers in these complex care situations.

Smart Homes

Some of the technology that will support independence among aging individuals has been considered in the planning for smart homes. Smart homes are living spaces designed with sensor networks, motion sensors, infrared cameras, and robots that provide interactive technologies and unobtrusive support systems to enable people to enjoy a higher level of independence, activity, participation, or well-being. Far from being part of a science fiction fantasy, today's IoT makes the possibilities of a smart home much more easily attainable. Smart homes can promote independent living and safety, and they can potentially optimize quality of life and reduce the stress and burden on aged-care facilities as well as on formal and informal caregivers.

Current technology allows smart homes to consolidate control of a broad range of systems, including lighting, temperature, security, and entertainment, in easily accessible electronic formats that can be operated through interactive touch commands or by voice. Future smart environments could sense change, predict normal and abnormal behaviors and physiologic trajectories, and alert users and caregivers to potentially dangerous behaviors or physiological changes. As individuals strive to maintain their independence, there is a need for monitoring that can identify changes that may put them at risk. Such monitoring could include changes in broader health markers that might suggest the risk of cognitive decline. As examples, smart home technologies have been demonstrated that can identify abnormalities in gait,[48] onset of infection,[49] and changes in cognitive functioning.[50] Smart communication technologies in the home have also been used to facilitate social connections,[51] relationships with healthcare providers, and tele-rehabilitation.[52]

Large-scale studies in smart homes are needed to assess the feasibility, validity, and reliability of functional monitoring and to compare the effectiveness of various technologies. In addition, research is needed to determine which parameters should be measured. Evaluation of optimal monitoring strategies and timing, usability issues, and cost should all be performed. Importantly, users' preferences should be explored to determine what they would like to know and with whom they wish

[47] https://www.aarp.org/content/dam/aarp/research/public_policy_institute/health/home-alone-family-caregivers-providing-complex-chronic-care-rev-AARP-ppi-health.pdf

[48] https://www.ncbi.nlm.nih.gov/pubmed/25405437

[49] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4444411/

[50] https://www.ncbi.nlm.nih.gov/pubmed/29107052

[51] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4417513/

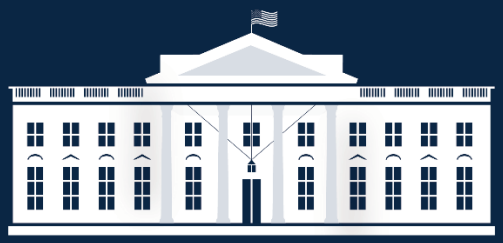
[52] https://ieeexplore.ieee.org/document/7002971/

to share that information. Compatibility among different smart home platforms should be considered to avoid overreliance on a particular vendor or solution.

For smart homes that are designed to monitor health or deliver treatments to older adults with chronic health conditions, the technology needs to be applied in a real-time, accessible, effective, and minimally obtrusive way. These are some examples of specific considerations for different areas of pathology or behavior:

- **Cardiovascular risk factors**: Most research to date in this area relies either on self-reported data (e.g., sedentary lifestyle) or measures evaluated infrequently when the research participant comes to a clinic (e.g., blood pressure or walking speed). These approaches may not accurately reflect the person's behavior/measures in the real world. Research on more real-world measures is needed.
- **Sleep patterns**: The interaction between sleep and aging is not well understood. It is unknown whether treating sleep problems will result in improved cognition in humans, and the potential impact may depend on both the nature and cause of the disordered sleep. Technology to aid in monitoring sleep, including the sleep stage, in a person's home may aid in understanding this interaction.
- **Social interactions**: The optimal frequency and type of social interaction that supports independence for older adults is not well understood. Research is needed in several areas, including identifying which of the many software and platform options work best to facilitate social interaction and for which people. A uniform solution is not likely to be appropriate because of the numerous factors impacting older adults, including variations in vision, hearing, and range of motion (e.g., due to arthritis).

In summary, smart homes should collect, integrate, process, analyze, communicate, and present data so that individuals are engaged and empowered in their own healthcare with reduced burden to care providers. Thus, research is needed to develop deployable smart home sensing packages tailored to meet the needs of individuals that are safe, reliable, and effective. Finally, best practice guidelines should be developed through public-private partnerships that are informed by the use of smart technology in community testbeds across a diverse range of communities.



THE WHITE HOUSE