Title

Diet and Activity Assessments and Interventions Using Technology in Older Adults.

Journal

American Journal of Preventive Medicine, 55(4)

Authors

Takemoto, Michelle

Manini, Todd

Rosenberg, Dori

et al.

Publication Date

2018-10-01

DOI

10.1016/j.amepre.2018.06.005

Peer reviewed

HHS Public Access

Author manuscript

Am J Prev Med. Author manuscript; available in PMC 2020 April 22.

Published in final edited form as:

Am J Prev Med. 2018 October ; 55(4): e105–e115. doi:10.1016/j.amepre.2018.06.005.

Diet and Activity Assessments and Interventions Using Technology in Older Adults

Michelle Takemoto, PhD[1], **Todd M. Manini, PhD**[2], **Dori E. Rosenberg, PhD, MPH**[3], **Amanda Lazar, PhD**[4], **Zvinka Z. Zlatar, PhD**[5], **Sai Krupa Das, PhD**[6], **Jacqueline Kerr, PhD**[1]

[1]Department of Family Medicine and Public Health, University of California, San Diego, La Jolla, California [2]Department of Aging and Geriatric Research, University of Florida, Gainesville, Florida [3]Kaiser Permanente Washington Health Research Institute, Seattle, Washington [4]College of Information Studies, University of Maryland, College Park, Maryland [5]Department of Psychiatry, University of California, San Diego, La Jolla, California [6]Energy Metabolism Laboratory, Jean Mayer USDA Human Nutrition Research Center on Aging, Tufts University, Boston, Massachusetts

Abstract

This paper reports on the findings and recommendations specific to older adults from the "Tech Summit: Innovative Tools for Assessing Diet and Physical Activity for Health Promotion" forum organized by the North American branch of the International Life Sciences Institute. The summit aimed to investigate current and emerging challenges related to improving energy balance behavior assessment and intervention via technology. The current manuscript focuses on how novel technologies are applied in older adult populations and enumerated the barriers and facilitators to using technology within this population. Given the multiple applications for technology in this population, including the ability to monitor health events and behaviors in real time, technology presents an innovative method to aid with the changes associated with aging. Although older adults are often perceived as lacking interest in and ability to adopt technologies, recent studies show they are comfortable adopting technology and user uptake is high with proper training and guided facilitation. Finally, the conclusions suggest recommendations for future research, including the need for larger trials with clinical outcomes and more research using end-user design that includes older adults as technology partners who are part of the design process.

INTRODUCTION

Older adults (aged 65 years and older) are a large and fast-growing population with a high rate of healthcare utilization and expenses. Increased focus on the costly healthcare issues associated with malnutrition or poor diet quality and lack of physical activity (PA) that increase demand for clinical care should be a research priority.[1,2] Even though there have

Address correspondence to: Michelle Takemoto, PhD, Department of Family Medicine and Public Health, University of California, San Diego, 9500 Gilman Dr., La Jolla CA 92093. mitakemoto@eng.ucsd.edu.

No other financial disclosures were reported by the authors of this paper.

been advances in the use of technology to assess and intervene on these lifestyle behaviors in younger adults,[3] companies and researchers are now turning their attention to enhancing "gerontechnology" to serve older adults. Although they continue to lag behind younger adults, older adults are becoming more technologically savvy, with an increasing percentage owning smartphones.[4] Further, as "baby boomers" transition into retirement, there will be a market of tech-informed older adults seeking appropriate support to maintain a healthy lifestyle in later life.

Older adults may particularly benefit from technological supports to help with recall and monitoring of behaveiors; however, barriers to using technology include challenging user interfaces or devices not specifically designed for those with the cognitive, visual, auditory, and tactile deficits commonly associated with aging. Technology designers must also recognize the large variability that exists within the older adult population. Although classified as "older adults," these individuals can vary widely in age by as much as 5 decades (i.e., 65105 years) and they experience varying levels of ability with different challenges and limitations. As age itself is not the only driver, designers and researchers must assess where along the aging-limitation continuum their target audience lies. Further, older adults may experience variability in functioning across days and weeks compared with younger adults because of chronic health conditions that can vary daily and can affect health related behaviors. In addition, systems must be flexible and attentive to daily needs and safe returns from periods of illness, which are more common in older adults. Older adults often experience a gradual decline in physical and cognitive functioning because of the aging process and accumulation or progression of disease. This calls attention to opportunities for self-monitoring, but it also requires designers to consider this trajectory and understand that maintenance is often preventive and does not necessarily reverse worsening trends.

Researchers should acknowledge other unique features of older adult lifestyle behaviors in technological solutions, including the settings or contexts in which behaviors occur. For example, 93.5% of older adults live in their own home compared with only 6.5% who reside in residential healthcare settings.[5] By contrast, young populations spend the majority of time in communal settings, such as schools or workplaces. This poses challenges to intervention delivery and creates differences in schedules and social support opportunities. The organizational and social factors in a workplace or school based setting may better support a sedentary behavior intervention using technology compared with a home environment[6,7]; therefore, technology has to be adapted to achieve change when used in isolation or it should provide a social component for those who are isolated. In contrast with younger adult populations, there may be more groups involved in the daily care of older adults, including family members, caregivers, and medical staff. There may be an increased need to share information with these groups and this raises unique ethical, privacy, and logistic considerations. Finally, relevant behaviors for younger populations may be less relevant for older adults and tools may need to address unique factors, such as falls prevention or hydration. Given the surge in technology for both measurement and interventions, better understanding of how to leverage its use with older adults is an important step for researchers. The purpose of this paper is to review and summarize the literature on methods and challenges for using technology with older adults. Specifically, this article provides an overview of current barriers to using technology for measurements and interventions.

Finally, the conclusions section discusses gaps in the literature and future directions for research to advance the field and leverage technology to improve health for older adults.

KEY LEARNINGS FOR DIETARY AND PHYSICAL ACTIVITY MEASUREMENT AND INTERVENTION USING TECHNOLOGY WITH OLDER ADULTS

Using technology to capture diet and PA behaviors in older adults poses opportunities because of unique features of these behaviors in older populations as well as challenges of using technology within this age group. Capturing dietary intake (DI) in older adults is critical for the prevention of nutrition-related disorders and disease conditions and for effective treatment of individuals with health problems.[8] Measuring DI requires assessments covering both ends of the spectrum of malnutrition—namely, prevention of weight gain and obesity[9] and avoidance of undernutrition.[10] Current methods of DI capture used with adults include 24-hour recalls, food logs, and food frequency questionnaires administered using traditional and technology-based methods. These methods are equally suitable for use with older adults, provided the individual can report intake without any constraints imposed by cognitive challenges and eating capabilities. However, in general, there are several challenges to collecting dietary data in older adults.[11,12] Some of these challenges are a direct result of the aging process, such as (1) diminished smell and taste that affect eating and appetite; (2) cognitive changes and memory loss that make it difficult to remember whether or not a meal took place, what was eaten, and whether or not the meal was logged; (3) changes in functionality that make procurement of food difficult; and (4) adjustments to living conditions that make food preparation difficult or not possible with food provided by caregivers or institutions. The complex interplay of health conditions, medications, and supplements older adults usually take, as well as the effects of alcohol and hydration, are additional factors for DI capture and provision of interventions. Therefore, effective dietary assessment necessitates clearly distinguishing between older adults who can provide accurate intake information and those for whom observational data are best for DI quantification.

Similar to unique dietary issues, older adults' PA behaviors differ from younger groups, leading to challenges in designing technologies for this group. For PA, thresholds of movement that consider absolute intensity (e.g., moderate- to vigorous-intensity movement) become less achievable over time as the aging process and chronic disease progression affects fitness and functioning; therefore, relative or lower thresholds are needed.[13] In addition, PA targets for older adults include balance and strength,[14] so devices supporting active aging need to be inclusive of behaviors beyond aerobic activity tracking. Further, many older adults do not meet PA guidelines[15]; therefore, emphasis on alternative behaviors, such as reducing sedentary behavior, may be more feasible.[16–20] Within the spectrum of movement detection in older adults, slower-paced movements, falls, and markers of increased frailty are as important as high-intensity activity.[14] In addition, where the movement occurs (i.e., tracking whether older adults maintain their mobility and life space by leaving their home on a daily basis) is also a priority not applicable to younger populations.[21–23]

Technological tools and interventions for older adults span a broad spectrum of behaviors (Tables 1 and 2), and findings from previous research indicate interventions and assessments using technology were feasible and efficacious in older adults.[5355] Additionally, activity monitors and DI technologies are a pervasive and rapidly growing methodology that is expected to shed light on the health effects of daily PA, sedentary patterns, and nutrient intake.[56] Further, older adults are generally responsive to wearing and using monitors and in particular, in a research context, they are generally compliant to wear protocols—occasionally more so than young adults.[57,58] However, additional research using these technologies in older adult populations is needed before they are scalable, with increased focus on user-centered design.

In general, older adults adopt technology less often and typically after younger populations do.[59,60] Older adults perceive and experience more barriers to mobile technology than younger adults, making them less likely to use it.[61,62] According to a recent Pew report,[63] 48% of seniors say the following statement describes them very well, “When I get a new electronic device, I usually need someone else to set it up or show me how to use it.” Although this age discrepancy is narrowing with the ubiquity of mobile technology, an age-related gap in adoption will likely remain. Thus, self-monitoring that requires user input (e.g., ecological momentary assessments or nutrition information) should consider barriers associated with using technology in this population. Common barriers include those originating from physical, acceptability, and technological factors.[64] The following sections describe these barriers and potential methods to overcome them.

Physical Barriers

Older adults have lower cognitive, motor, and sensory function than younger adults.[65] Decreases in working memory and spatial acuity can impair an older adult’s ability to navigate hierarchical menus. Dexterity and fine motor movements are more difficult, and thus interaction with mobile data collection instruments can result in errors because of inaccurate selections.[61,64,66]

Employment of focus groups to assess technology before its full implementation could identify potential issues with the user interface as a possible solution to the physical barriers described above. Additionally, customized user interfaces may be necessary to overcome a variety of mixed physical barriers to technology use. Cognitive screening could identify individuals who would likely have difficulty interfacing with technology before observation, and additional training provided to those participants to facilitate uptake.

Acceptability Barriers

Perceived ease of use is a critical aspect of technology adoption.[66–68] Activity and nutrition monitoring technology can be overwhelming for older adults because of their limited experience with and knowledge of mobile devices.[64] They also lack confidence in and underestimate their ability for using devices.[66,69]

To overcome these acceptability barriers, practitioners and researchers should provide clear and concise instructions containing visuals. A trial period and follow-up conversations about usability are important to help build self-efficacy. Previous studies showed older adults with

lower self-efficacy were less likely to use technology; therefore, including opportunities for individuals to receive positive feedback during training and experience small successes is essential.[70,71] In addition, a direct contact person should be available for questions when technology malfunctions. Finally, including end-users in pretesting workshops to explain the technology may be an effective means to facilitate uptake and adoption.

Technological Barriers

Most hardware and software technology is not designed for older adults.[72] As a result, older adults often have difficulty with recognizing icons,[73] get lost in device menus,[74] have poor response to tap functions on touch screens,[75] and are concerned about battery depletion.[68] Older adults could benefit from having customized software and haptic aids with larger icons, simpler device menus, and touchscreen functions as a method to overcome technological barriers for use.

Data Interpretation Barriers

An additional barrier for older adults is the interpretation of data originating from activity monitors. Most commercial monitors use proprietary algorithms to estimate activity estimates, which makes it challenging to use these devices in research studies. Additionally, when using accelerometers, ideally the output maps onto the metabolic intensity of movement and thus serves as a way to record the frequency, duration, and intensity of PA patterns.[76] The accelerometer signal is preprocessed and converted into units attributable to human movement. These units, called activity counts or counts per minute, represent a quantitative measurement of movement that equates to a magnitude of acceleration over a specific unit of time.[56] Therefore, the output from an activity monitor is directly proportional to movement velocity, in that faster and more forceful footfalls register higher counts with a hip-worn monitor. For example, the 2003–2004 National Health and Nutrition Examination Survey used a single activity count threshold to objectively categorize the population's PA level and engagement in moderate to vigorous physical activity (MVPA).[15] Although these efforts are noteworthy, the output from the accelerometer and cutpoints used to define categories of activity level might misclassify people who move more slowly, yet achieve a metabolic rate consistent with the recommended activity intensity. This misclassification is particularly true for older adults who ambulate at a slower pace than younger adults ambulate, but have a sufficient metabolic rate to categorize that activity as meeting MVPA guidelines.[77,78] A recent study[79] demonstrated older adults who walked at a usual pace ≥1.0 m/s met the suggested MVPA metabolic intensity level and achieved an activity count threshold consistent with young adults. Older adults with a habitual walking pace <1.0 m/s were unable to achieve this threshold, yet they exceeded the metabolic intensity for MVPA. These results indicated a misclassification of older adults with slow habitual walking speed as not performing MVPA according to cutpoints used in young adults. In addition, the sensitivity of some accelerometers may be compromised at slower walking speeds, further compounding the problem.[79]

Monitoring in the Context of Health Events

Mobile technology allows a unique opportunity to understand activity and nutrition patterns before and after an intervening health event (IHE). An IHE is an episodic fall, injury, illness,

or hospitalization that results in restricted activity. IHEs are an emerging scientific area in geriatrics and gerontology because they are strong precipitants of acute losses in physical function[80,81] and contribute to the initial onset of common geriatric syndromes, such as frailty and cognitive impairment.[82–84] Most theoretic frameworks of disability explain age-related losses in physical function, increased disability, and dependency through insidious and catastrophic pathways.[85–87] Although the literature on insidious progression of disability is rich,[87–90] the contribution from catastrophic events is not well understood because of their episodic nature. Unfortunately, much of the knowledge about trajectories of change originates from retrospective proxy or self-reports of mobility or PA levels prior to the IHE. Technology can play an important role in this field by continuously monitoring individuals for a long period to measure preceding-event data to build risk profiles and base post-event recovery patterns.[46] Filling in this gap will allow practitioners to better target interventions for early risk factors of IHEs that aim to accelerate activity recovery or nutritional modifications following an IHE.

GAPS AND FUTURE NEEDS

Older adults' perceived lack of interest in and inability to use technology is often cited as a barrier to technological interventions within this population; however, research findings challenged these assumptions and found that older adults were interested in and capable of using technology.[91,92] At the same time, many characteristics affect individuals' willingness to adopt technologies. For example, individuals are more likely to use technologies when they perceive them as beneficial or useful.[91–95] One way to improve the likelihood a technology will be adopted and used by older adults is to incorporate their needs and preferences into the design and implementation of technology interventions and design systems with the capability of tracking multiple outcomes, such as medication use, food intake, PA, and completion of activities of daily living. An approach to designing technology for this population is to utilize mixed methods by incorporating qualitative methodology.[96] Researchers utilized a variety of methodologies to design technologies for health targeting older adults, including photo elicitations,[97] contextual inquiries,[98] participatory design,[99] storytelling methodology as a way to frame design,[100,101] focus groups,[102] and interviews.[103] These methods facilitate co-design during formative and evaluative stages of the research process to improve user uptake and adherence. However, even when older adults were included in research at early stages, deeply ingrained assumptions and stereotypes about older adults influenced researchers' ability to take into account user preferences and needs.[104–106] Encouraging older adults, family members, caregivers, and medical professionals to participate throughout the entire design process to help shape the direction of research can potentially reduce the way researcher bias affects the interpretation of outcomes and findings.

Community advisory boards seek to support researchers in understanding and addressing ethical issues, risks and benefits of research, obtaining consent for technology-based interventions,[107] and gathering and sharing data in older adults. Older adults may have differing definitions of risk regarding data control compared with younger populations.[108] Thus, future research should support older adults with differing abilities to participate in decision making around using technologies to maintain health.

Even with older adults' expanding use of technology, behavior change outcomes appear stronger in programs that provide personal accountability and human interaction,[39,40] perhaps in part because their technology literacy is lower than younger populations.[109] In one study with older adults, providing a PA wearable device without one-on-one instruction on how to use it or coaching did not result in high adherence.[92] Furthermore, technologies vary based on acceptance and physical and mental capabilities and may require personalization that increases the challenge of designing effective tools. Technologies focus mostly on self-monitoring tools, but lack the action planning and problem solving that a health coach can provide. Further, technology-based tools provide a different type of accountability and social support than a personal coach.[53] In a focus group with older adults around technology, the accountability of a human was important.[110] Human coaches can provide these important behavior change strategies in complement with technology. To date, no studies have directly compared wearable devices alone with wearable devices plus health coaching in general older adult populations, but there is strong evidence of the effectiveness of health coaching in other populations.[35,36,65] For example, a previous study with a younger population indicated that adding a wearable device alone does not improve exercise efficacy.[54]

Having human support will likely increase accountability and enhance use of devices that support behavior change. However, this contact can occur through telehealth or by phone and does not necessarily need to be conducted in-person or by a professional.[111–113] Furthermore, technology alone may be sufficient for some older adults, whereas others may need more individually tailored human-based support or coaching. Future studies using Sequential, Multiple Assignment, Randomized Trial design methodologies, for example, can better elucidate the types of technology interventions that work best for different types of older adults.[55,114]

Lessons from development of machine-learned activity classifiers in older adults provide direction for the field. In contrast with younger adults whose behaviors in laboratory settings may reflect their daily behaviors, many older adults do not move in free living as they do during short clinical tests in a supervised setting.[13,77,79] Behavior classifiers from laboratory settings or young populations do not predict behaviors in older adults. Therefore, future research should study this population in their natural context. Further, although behaviors themselves may be health targets in some populations, the clinical impact of new data processing techniques is equally important in older adults. Few studies have compared new machine-learned classifiers versus traditional cutpoint approaches to accelerometer data in their ability to predict health outcomes. There are many large cohort studies with well-adjudicated health outcomes using accelerometers to help ascertain if more complex computation procedures result in clinical gain.[58,115–117] Although new techniques appear to be more accurate, researchers should weigh the additional challenges of data resolution, processing, and storage against the clinical benefits. In particular, the additional monitoring must provide benefits that are not otherwise achievable from other methods. For example, a nurse in a clinical care setting will be alerted to important major events, such as a fall; the nurse does not need to review the continuous stream of data to obtain this information.

CONCLUSIONS

A key finding for this conceptual review of lifestyle behaviors, technology, and older adults is that research is in its infancy and is limited to small pilot trials. Although larger trials are needed with clinical outcomes in due course, more time should be expended on designing tools and interventions for the growing population of older adults as technology partners and consumers rather than recipients. Further, researchers must consider settings, providers, and caregivers at the design stage.

Given the growing market that older adults' health care presents, researchers should work with companies to include older adults' perspectives, provide evidence-based interventions, and learn from data collected on larger groups that are often available in research settings. In contrast with younger populations in which changes can be infrequent and clinical events not observable, older adults have health challenges to study to improve future prediction and prevention of such events. Technology can aid with aging-associated changes, when positively framed for older adults, in that it can facilitate their engagement with life and maintain their independence in their community.

ACKNOWLEDGMENTS

This review was inspired by discussions at a 2016 expert forum ("Tech Summit: Innovative Tools for Assessing Diet and Physical Activity for Health Promotion"), which was organized by the North American Branch of the International Life Sciences Institute (ILSI North America) with the help of scientists from the University of California, San Diego (UCSD), the U.S. Department of Agriculture Agricultural Research Service, the American College of Sports Medicine (ACSM), and NIH. In-kind support was received from UCSD and financial contributions were provided by ACSM and the ILSI North America Committee on Balancing Food and Activity for Health. Additional funding from the ILSI North America Committee on Balancing Food and Activity for Health was allocated for the preparation and publication of papers following the forum. ILSI North America is a public, non-profit foundation that provides a forum to advance understanding of scientific issues related to the nutritional quality and safety of the food supply by sponsoring research programs, educational seminars and workshops, and publications. ILSI North America receives support primarily from its industry membership. The opinions expressed herein are those of the authors and do not necessarily represent the views of the funding organization. Michelle Takemoto received an honorarium from ILSI North America. Todd Manini was supported by a grant from NIH (P30AG028740) for this work. This article has been reviewed and approved for submission to the *American Journal* of *Preventive Medicine* by ILSI North America. ILSI North America had no role in the study design; collection, analysis, and interpretation of data; writing the report; and the decision to submit the report for publication.

THEME NOTE

This article is part of a theme issue entitled Innovative Tools for Assessing Diet and Physical Activity for Health Promotion, which is sponsored by the North American branch of the International Life Sciences Institute.

REFERENCES

1. Martinson BC, Crain AL, Pronk NP, O'Connor PJ, Maciosek MV. Changes in physical activity and short-term changes in health care charges: a prospective cohort study of older adults. Prev Med. 2003;37(4):319–326. 10.1016/S0091-7435(03)00139-7. [PubMed: 14507488]
2. Anderson LH, Martinson BC, Crain AL, et al. Healthcare charges associated with physical inactivity, overweight, and obesity. Prev Chronic Dis. 2005;2(4):A09..
3. Stephens J, Allen J. Mobile phone interventions to increase physical activity and reduce weight: a systematic review. J Cardiovasc Nurs. 2013;28(4):320–329. 10.1097/JCN.0b013e318250a3e7. [PubMed: 22635061]
4. Anderson M For vast majority of seniors who own one, a smartphone equals "freedom." www.pewresearch.org/fact-tank/2015/04/29/seniors-smartphones/. Published 2015. Accessed November 15, 2017.

5. National Academy of Medicine. Size and demographics of aging populations Providing Healthy and Safe Foods as We Age: Workshop Summary. Washington, DC: National Academies Press; 2010:17–38. 10.17226/12967.
6. Buman MP, Mullane SL, Toledo MJ, et al. An intervention to reduce sitting and increase light-intensity physical activity at work: design and rationale of the "Stand & Move at Work" group randomized trial. Contemp Clin Trials. 2017;53(suppl C):11–19. 10.1016/j.cct.2016.12.008. [PubMed: 27940181]
7. Neuhaus M, Healy GN, Dunstan DW, Owen N, Eakin EG. Workplace sitting and height-adjustable workstations: a randomized controlled trial. Am J Prev Med. 2014;46(1):30–40. 10.1016/j.amepre.2013.09.009. [PubMed: 24355669]
8. Astell AJ, Hwang F, Brown LJ, et al. Validation of the NANA (Novel Assessment of Nutrition and Ageing) touch screen system for use at home by older adults. Exp Gerontol. 2014;60:100–107. 10.1016/j.exger.2014.10.008. [PubMed: 25456843]
9. Kennedy RL, Malabu U, Kazi M, Shahsidhar V. Management of obesity in the elderly: too much and too late? J Nutr Health Aging.2008;12(9):608–621. [PubMed: 18953458]
10. Chau D, Cho LM, Jani P, St Jeor ST. Individualizing recommendations for weight management in the elderly. Curr Opin Clin Nutr Metab Care. 2008;11(1):27–31. 10.1097/MCO.0b013e3282f31744. [PubMed: 18090654]
11. van Staveren WA, de Groot LC, Blauw YH, van der Wielen RP. Assessing diets of elderly people: problems and approaches. Am J Clin Nutr. 1994;59(1):221S–223S. (suppl) 10.1093/ajcn/59.1.221S. [PubMed: 8279429]
12. de Vries JH, de Groot LC, van Staveren WA. Dietary assessment inelderly people: experiences gained from studies in the Netherlands. Eur J Clin Nutr. 2009;63(suppl 1):S69–S74. 10.1038/ejcn.2008.68. [PubMed: 19190649]
13. Evenson KR, Buchner DM, Morland KB. Objective measurement of physical activity and sedentary behavior among U.S. adults aged 60 years or older. Prev Chronic Dis. 2012;9:E26. [PubMed: 22172193]
14. WHO. Physical activity and older adults. www.who.int/dietphysicalactivity/factsheet_olderadults/en/. Geneva, Switzerland: WHO. Published 2018. Accessed April 3, 2018.
15. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008;40(1):181–188. 10.1249/mss.0b013e31815a51b3. [PubMed: 18091006]
16. Fitzsimons CF, Kirk A, Baker G, Michie F, Kane C, Mutrie N. Using an individualised consultation and activPAL feedback to reduce sedentary time in older Scottish adults: results of a feasibility and pilot study. Prev Med. 2013;57(5):718–720. 10.1016/j.ypmed.2013.07.017. [PubMed: 23891853]
17. Manini TM, Carr LJ, King AC, Marshall S, Robinson TN, Rejeski WJ. Interventions to reduce sedentary behavior. Med Sci Sports Exerc. 2015;47(6):1306–1310. 10.1249/MSS.0000000000000519. [PubMed: 25222818]
18. Gardiner PA, Eakin EG, Healy GN, Owen N. Feasibility of reducing older adults' sedentary time. Am J Prev Med. 2011;41(2):174–177. 10.1016/j.amepre.2011.03.020. [PubMed: 21767725]
19. Rosenberg DE, Gell NM, Jones SMW, et al. The feasibility of reducing sitting time in overweight and obese older adults. Health Educ Behav. 2015;42(5):669–676. 10.1177/1090198115577378. [PubMed: 25794518]
20. Kerr J, Takemoto M, Bolling K, et al. Two-arm randomized pilot intervention trial to decrease sitting time and increase sit-to-stand transitions in working and non-working older adults. PLoS One. 2016;11(1):e0145427 10.1371/journal.pone.0145427. [PubMed: 26735919]
21. Takemoto M, Carlson JA, Moran K, Godbole S, Crist K, Kerr J. Relationship between objectively measured transportation behaviors and health characteristics in older adults. Int J Environ Res Public Health. 2015;12(11):13923–13937. 10.3390/ijerph121113923. [PubMed: 26528999]
22. Kotani K, Morii M, Asai Y, Sakane N. Application of mobile-phone cameras to home health care and welfare in the elderly: experience in a rural practice. Aust J Rural Health. 2005;13(3):193–194. 10.1111/j.1440-1854.2005.00682.x. [PubMed: 15932491]

23. Petersen J, Austin D, Kaye JA, Pavel M, Hayes TL. Unobtrusive in-home detection of time spent out-of-home with applications to loneliness and physical activity. IEEE J Biomed Health Inform. 2014;18 (5):1590–1596. 10.1109/JBHI.2013.2294276. [PubMed: 25192570]
24. Corbett DB, Valiani V, Knaggs JD, Manini TM. Evaluating walking intensity with hip-worn accelerometers in elders. Med Sci Sports Exerc. 2016;48(11):2216–2221. 10.1249/MSS.0000000000001018. [PubMed: 27327031]
25. Rosenberg D, Godbole S, Ellis K, et al. Classifiers for accelerometer-measured behaviors in older women. Med Sci Sports Exerc. 2017;49 (3):610–616. 10.1249/MSS.0000000000001121. [PubMed: 28222058]
26. Ellis K, Kerr J, Godbole S, Staudenmayer J, Lanckriet G. Hip andwrist accelerometer algorithms for free-living behavior classification. Med Sci Sports Exerc. 2016;48(5):933–940. 10.1249/MSS.0000000000000840. [PubMed: 26673126]
27. Kaye JA, Maxwell SA, Mattek N, et al. Intelligent systems for assessing aging changes: home-based, unobtrusive, and continuous assessment of aging. J Gerontol B Psychol Sci Soc Sci. 2011;66B(suppl 1): i180–i190. 10.1093/geronb/gbq095.
28. Schwenk M, Howe C, Saleh A, et al. Frailty and technology: a systematic review of gait analysis in those with frailty. Gerontology. 2014;60 (1):79–89. 10.1159/000354211. [PubMed: 23949441]
29. Danielsen A, Olofsen H, Bremdal BA. Increasing fall risk awareness using wearables: a fall risk awareness protocol. J Biomed Inform. 2016;63:184–194. 10.1016/j.jbi.2016.08.016. [PubMed: 27544413]
30. Rosevall J, Rusu C, Talavera G, et al. A wireless sensor insole for collecting gait data. Stud Health Technol Inform. 2014;200:176–178. 10.3233/978-1-61499-393-3-176. [PubMed: 24851988]
31. Landau R, Werner S, Auslander GK, Shoval N, Heinik J. Attitudes of family and professional care-givers towards the use of GPS for tracking patients with dementia: an exploratory study. Br J Soc Work. 2009;39(4):670–692. 10.1093/bjsw/bcp037.
32. Pot AM, Willemse BM, Horjus S. A pilot study on the use of tracking technology: feasibility, acceptability, and benefits for people in early stages of dementia and their informal caregivers. Aging Ment Health. 2012;16(1):127–134. 10.1080/13607863.2011.596810. [PubMed: 21780960]
33. Doherty AR, Moulin CJ, Smeaton AF. Automatically assisting human memory: a SenseCam browser. Memory. 2011;19(7):785–795. 10.1080/09658211.2010.509732. [PubMed: 20845223]
34. Eyles H, McLean R, Neal B, et al. A salt-reduction smartphone app supports lower-salt food purchases for people with cardiovascular disease: findings from the SaltSwitch randomised controlled trial. Eur J Prev Cardiol. 2017;24(13):1435–1444. 10.1177/2047487317715713. [PubMed: 28631933]
35. King AC, Winter SJ, Sheats JL, et al. Leveraging citizen science and information technology for population physical activity promotion. Transl J Am Coll Sports Med. 2016;1(4):30–44. [PubMed: 27525309]
36. King AC, Hekler EB, Grieco LA, et al. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. PLoS One. 2013;8(4): e62613 10.1371/journal.pone.0062613. [PubMed: 23638127]
37. Wijsman CA, Westendorp RG, Verhagen EA, et al. Effects of a web-based intervention on physical activity and metabolism in older adults: randomized controlled trial. J Med Internet Res. 2013;15(11): e233 10.2196/jmir.2843. [PubMed: 24195965]
38. Antoine Parker C, Ellis R. Effect of electronic messaging on physical activity participation among older adults. J Aging Res.2016;2016:6171028. 10.1155/2016/6171028.
39. Baxter S, Johnson M, Payne N, et al. Promoting and maintaining physical activity in the transition to retirement: a systematic review of interventions for adults around retirement age. Int J Behav Nutr Phys Act. 2016;13:12 10.1186/s12966-016-0336-3. [PubMed: 26830026]
40. Abedtash H, Holden RJ. Systematic review of the effectiveness of health-related behavioral interventions using portable activity sensing devices (PASDs). J Am Med Inform Assoc. 2017;24(5):1002–1013. 10.1093/jamia/ocx006. [PubMed: 28339620]
41. Rosenberg DE, Lee AK, Anderson M, et al. Reducing sedentary timefor obese older adults: protocol for a randomized controlled trial. JMIR Res Protoc. 2018;7(2):e23 10.2196/resprot.8883. [PubMed: 29434012]

42. Gomersall SR, Ng N, Burton NW, Pavey TG, Gilson ND, Brown WJ. Estimating physical activity and sedentary behavior in a free-living context: a pragmatic comparison of consumer-based activity trackers and ActiGraph accelerometry. J Med Internet Res. 2016;18(9):e239 10.2196/jmir.5531. [PubMed: 27604226]
43. O'Brien T, Troutman-Jordan M, Hathaway D, Armstrong S, Moore M. Acceptability of wristband activity trackers among community dwelling older adults. Geriatr Nurs. 2015;36(suppl2): S21–S25. 10.1016/j.gerinurse.2015.02.019. [PubMed: 25771957]
44. Baram Y Virtual sensory feedback for gait improvement in neurological patients. Front Neurol. 2013;4:138 10.3389/fneur.2013.00138. [PubMed: 24133478]
45. Sungkarat S, Fisher BE, Kovindha A. Efficacy of an insole shoe wedge and augmented pressure sensor for gait training in individuals with stroke: a randomized controlled trial. Clin Rehabil. 2011;25(4):360–369. 10.1177/0269215510386125. [PubMed: 21148267]
46. Ma CZ, Wong DW, Lam WK, Wan AH, Lee WC. Balance improvement effects of biofeedback systems with state-of-the-art wearable sensors: a systematic review. Sensors (Basel). 2016;16(4):434 10.3390/s16040434. [PubMed: 27023558]
47. van Het Reve E, Silveira P, Daniel F, Casati F, de Bruin ED. Tablet-based strength-balance training to motivate and improve adherence to exercise in independently living older people: part 2 of a phase II preclinical exploratory trial. J Med Internet Res. 2014;16(6):e159 10.2196/jmir.3055. [PubMed: 24966165]
48. Bell CS, Fain E, Daub J, et al. Effects of Nintendo Wii on quality of life, social relationships, and confidence to prevent falls. Phys Occup Ther Geriatr. 2011;29(3):213–221. 10.3109/02703181.2011.559307.
49. Chao YY, Scherer YK, Wu YW, Lucke KT, Montgomery CA. The feasibility of an intervention combining self-efficacy theory and Wii Fit exergames in assisted living residents: a pilot study. Geriatr Nurs. 2013;34(5):377–382. 10.1016/j.gerinurse.2013.05.006. [PubMed: 23764366]
50. Hamm J, Money AG, Atwal A, Paraskevopoulos I. Fall prevention intervention technologies: a conceptual framework and survey of the state of the art. J Biomed Inform. 2016;59:319–345. 10.1016/j.jbi.2015.12.013. [PubMed: 26773345]
51. Joe J, Demiris G. Older adults and mobile phones for health: a review. J Biomed Inform. 2013;46(5):947–954. 10.1016/j.jbi.2013.06.008. [PubMed: 23810858]
52. Liddle J, Ireland D, McBride SJ, et al. Measuring the lifespace of people with Parkinson's disease using smartphones: proof of principle. JMIR Mhealth Uhealth. 2014;2(1):e13 10.2196/mhealth.2799. [PubMed: 25100206]
53. Lyons EJ, Swartz MC, Lewis ZH, Martinez E, Jennings K. Feasibility and acceptability of a wearable technology physical activity intervention with telephone counseling for mid-aged and older adults: a randomized controlled pilot trial. JMIR Mhealth Uhealth. 2017;5(3):e28 10.2196/mhealth.6967. [PubMed: 28264796]
54. Jakicic JM, Davis KK, Rogers RJ, et al. Effect of wearable technology combined with a lifestyle intervention on long-term weight loss: the IDEA randomized clinical trial. JAMA. 2016;316(11):1161–1171. 10.1001/jama.2016.12858. [PubMed: 27654602]
55. Hinman RS, Delany CM, Campbell PK, Gale J, Bennell KL. Physical therapists, telephone coaches, and patients with knee osteoarthritis: qualitative study about working together to promote exercise adherence. Phys Ther. 2016;96(4):479–493. 10.2522/ptj.20150260. [PubMed: 26316529]
56. Troiano RP, McClain JJ, Brychta RJ, Chen KY. Evolution of accelerometer methods for physical activity research. Br J Sports Med. 2014;48(13):1019–1023. 10.1136/bjsports-2014-093546. [PubMed: 24782483]
57. Pahor M, Guralnik JM, Ambrosius WT, et al. Effect of structured physical activity on prevention of major mobility disability in older adults: the LIFE study randomized clinical trial. JAMA. 2014;311 (23):2387–2396. 10.1001/jama.2014.5616. [PubMed: 24866862]
58. Evenson KR, Wen F, Herring AH, et al. Calibrating physical activity intensity for hip-worn accelerometry in women age 60 to 91 years: the Women's Health Initiative OPACH Calibration Study. Prev Med Rep. 2015;2(suppl C):750–756. 10.1016/j.pmedr.2015.08.021. [PubMed: 26527313]

59. File T. Computer and Internet use in the United States. Current Population Survey Reports. P20–568. Washington, DC: U.S. Census Bureau www.census.gov/content/dam/Census/library/publications/2013/demo/p20-569.pdf. Published May 2013. Accessed June 11, 2018.
60. Smith A Older adults and technology use. Washington, DC: Pew Research Center www.pewinternet.org/2014/04/03/older-adultsand-technology-use/. Published April 3, 2014. Accessed November 15, 2017.
61. Fletcher J, Jensen R. Mobile health: barriers to mobile phone use in the aging population. Online J Nurs Inform. 2015;19(3).
62. Pew Research Center. Mobile fact sheet. Washington, DC: Pew Research Center; 2018: www.pewinternet.org/fact-sheet/mobile/.
63. Anderson M, Perrin A. Tech adoption climbs among older adults. www.pewinternet.org/2017/05/17/tech-adoption-climbsamong-older-adults/. Published 2017. Accessed January 1, 2018.
64. Wallace S, Graham C, Saraceno A. Older adults' use of technology. Persp Gerontol. 2013;18(2):50–59. 10.1044/gero18.2.50.
65. French DP, Olander EK, Chisholm A, Mc Sharry J. Which behaviour change techniques are most effective at increasing older adults' self-efficacy and physical activity behaviour? A systematic review. Ann Behav Med. 2014;48(2):225–234. 10.1007/s12160014-9593-z. [PubMed: 24648017]
66. Barnard Y, Bradley MD, Hodgson F, Lloyd AD. Learning to use new technologies by older adults: perceived difficulties, experimentation behaviour and usability. Comput Hum Behav. 2013;29(4):1715–1724. 10.1016/j.chb.2013.02.006.
67. Deng Z, Mo X, Liu S. Comparison of the middle-aged and older users' adoption of mobile health services in China. Int J Med Inform. 2014;83(3):210–224. 10.1016/j.ijmedinf.2013.12.002. [PubMed: 24388129]
68. Parker SJ, Jessel S, Richardson JE, Reid MC. Older adults are mobile too! Identifying the barriers and facilitators to older adults' use of mHealth for pain management. BMC Geriatr. 2013;13:43 10.1186/1471-2318-13-43. [PubMed: 23647949]
69. Ziefle M, Bay S. How older adults meet complexity: aging effects on the usability of different mobile phones. Behav Inform Technol. 2005;24(5):375–389. 10.1080/0144929042000320009.
70. Czaja SJ, Charness N, Fisk AD, et al. Factors predicting the use of technology: findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). Psychol Aging. 2006;21(2):333–352. 10.1037/0882-7974.21.2.333. [PubMed: 16768579]
71. Ellis D, Allaire JC. Modeling computer interest in older adults: the role of age, education, computer knowledge, and computer anxiety. Hum Factors. 1999;41(3):345–355. 10.1518/001872099779610996. [PubMed: 10665203]
72. Wandke H, Sengpiel M, Sonksen M. Myths about older people's use of information and communication technology. Gerontology. 2012;58(6):564–570. 10.1159/000339104. [PubMed: 22739502]
73. Santa-Rosa JG, Fernandes H. Application and analysis of the affinities diagram on the examination of usability problems among older adults. Work. 2012;41(suppl 1):328–332. 10.3233/WOR-2012-0177-328. [PubMed: 22316744]
74. Arning K, Ziefle M. Effects of age, cognitive, and personal factors on PDA menu navigation performance. Behav Inform Technol. 2009;28 (3):251–268. 10.1080/01449290701679395.
75. Zhou J, Rau P-LP, Salvendy G. Older adults' use of smart phones: an investigation of the factors influencing the acceptance of new functions. Behav Inform Technol. 2014;33(6):552–560. 10.1080/0144929X.2013.780637.
76. Hall KS, Howe CA, Rana SR, Martin CL, Morey MC. METs and accelerometry of walking in older adults: standard versus measured energy cost. Med Sci Sports Exerc. 2013;45(3):574–582. 10.1249/MSS.0b013e318276c73c. [PubMed: 23059862]
77. Hall KS, Morey MC, Dutta C, et al. Activity-related energy expenditure in older adults: a call for more research. Med Sci Sports Exerc. 2014;46 (12):2335–2340. 10.1249/MSS.0000000000000356. [PubMed: 24714651]
78. Knaggs JD, Larkin KA, Manini TM. Metabolic cost of daily activities and effect of mobility impairment in older adults. J Am Geriatr Soc. 2011;59(11):2118–2123. 10.1111/j.1532-5415.2011.03655.x. [PubMed: 22091979]

79. Abel MG, Hannon JC, Sell K, Lillie T, Conlin G, Anderson D. Validation of the Kenz Lifecorder EX and ActiGraph GT1M accelerometers for walking and running in adults. Appl Physiol Nutr Metab. 2008;33 (6):1155–1164. 10.1139/h08-103. [PubMed: 19088773]
80. Zaslavsky O, Zisberg A, Shadmi E. Impact of functional change before and during hospitalization on functional recovery 1 month following hospitalization. J Gerontol A Biol Sci Med Sci. 2015;70 (3):381–386. 10.1093/gerona/glu168. [PubMed: 25199914]
81. Fimognari FL, Pierantozzi A, De Alfieri W, et al. The severity of acute illness and functional trajectories in hospitalized older medical patients. J Gerontol A Biol Sci Med Sci. 2017;72(1):102–108. 10.1093/gerona/glw096. [PubMed: 27257216]
82. Zisberg A, Sinoff G, Agmon M, Tonkikh O, Gur-Yaish N, Shadmi E.Even a small change can make a big difference: the case of in-hospital cognitive decline and new IADL dependency. Age Ageing. 2016;45 (4):500–504. 10.1093/ageing/afw063. [PubMed: 27085179]
83. Calero-Garcia MJ, Ortega AR, Navarro E, Calero MD. Relationship between hospitalization and functional and cognitive impairment in hospitalized older adults patients. Aging Ment Health. 2017;21 (11):1164–1170. 10.1080/13607863.2016.1220917. [PubMed: 27564919]
84. Beishuizen SJ, van Munster BC, de Jonghe A, Abu-Hanna A, Buur-man BM, de Rooij SE. Distinct cognitive trajectories in the first year after hip fracture. J Am Geriatr Soc. 2017;65(5):1034–1042. 10.1111/jgs.14754. [PubMed: 28152178]
85. Gill TM, Allore H, Holford TR, Guo Z. The development of insidious disability in activities of daily living among community-living older persons. Am J Med. 2004;117(7):484–491. 10.1016/j.amjmed.2004.05.018. [PubMed: 15464705]
86. Guralnik JM, Ferrucci L, Balfour JL, Volpato S, Di Iorio A. Progressive versus catastrophic loss of the ability to walk: implications for the prevention of mobility loss. J Am Geriatr Soc. 2001;49(11):1463–1470. 10.1046/j.1532-5415.2001.4911238.x. [PubMed: 11890584]
87. Ferrucci L, Guralnik JM, Simonsick E, Salive ME, Corti C, Langlois J. Progressive versus catastrophic disability: a longitudinal view of the disablement process. J Gerontol A Biol Sci Med Sci. 1996;51(3): M123–M130. 10.1093/gerona/51A.3.M123. [PubMed: 8630705]
88. Spiers NA, Matthews RJ, Jagger C, et al. Diseases and impairments as risk factors for onset of disability in the older population in England and Wales: findings from the Medical Research Council CognitiveFunction and Ageing Study. J Gerontol A Biol Sci Med Sci. 2005;60(2):248–254. 10.1093/gerona/60.2.248. [PubMed: 15814870]
89. Manton KG, Stallard E, Corder LS. The dynamics of dimensions of age-related disability 1982 to 1994 in the U.S. elderly population. J Gerontol A Biol Sci Med Sci. 1998;53(1):B59–B70. 10.1093/gerona/53A.1.B59. [PubMed: 9467424]
90. Gill TM, Hardy SE, Williams CS. Underestimation of disability in community-living older persons. J Am Geriatr Soc. 2002;50:1599–1601. 10.1046/j.1532-5415.2002.50403.x. [PubMed: 12383164]
91. Mitzner TL, Boron JB, Fausset CB, et al. Older adults talk technology: technology usage and attitudes. Comput Human Behav. 2010;26 (6):1710–1721. 10.1016/j.chb.2010.06.020. [PubMed: 20967133]
92. Rosenberg D, Kadokura EA, Bouldin ED, Miyawaki CE, Higano CS, Hartzler AL. Acceptability of Fitbit for physical activity tracking within clinical care among men with prostate cancer. AMIA Annu Symp Proc. 2016;2016:1050–1059. [PubMed: 28269902]
93. Melenhorst AS, Rogers WA, Caylor EC. The use of communication technologies by older adults: exploring the benefits from the user's perspective. Proc Hum Factors Ergon Soc Annu Meet. 2001;45 (3):221–225. 10.1177/154193120104500305.
94. Heinz M, Martin P, Margrett JA, et al. Perceptions of technology among older adults. J Gerontol Nurs. 2013;39(1):42–51. 10.3928/00989134-20121204-04.
95. McCreadie C, Tinker A. The acceptability of assistive technology to older people. Ageing Soc. 2005;25(1):91–110. 10.1017/S0144686X0400248X .
96. Fisk AD, Czaja SJ, Rogers WA, Charness N, Sharit J. Designing for Older Adults: Principles and Creative Human Factors Approaches. Boca Raton, FL: CRC Press; 2009: 10.1201/9781420080681.

97. Lim C, Berry ABL, Hirsch T, et al. “It just seems outside my health”: how patients with chronic conditions perceive communication boundaries with providers. DIS (Des Interact Syst Conf).2016;2016:1172–1184. 10.1145/2901790.2901866. [PubMed: 28804790]

98. Hirsch T, Lim C, Otten JJ. What’s for lunch? A socio-ecological approach to childcare nutrition. In: Proceedings of the 2016 ACM Conference on Designing Interactive Systems New York, NY: Association for Computing Machinery, 2016:1160–1171. 10.1145/2901790.2901793 .

99. Vines J, Blythe M, Dunphy P, et al. Cheque mates: participatory design of digital payments with eighty somethings. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems New York, NY: Association for Computing Machinery, 2012:1189–1198. 10.1145/2207676.2208569.

100. Caprani N, Gurrin C, O’Connor NE. I like to log: a questionnaire study towards accessible lifelogging for older users. In: Proceedings of the 12th International ACM SIGACCESS Conference on Computers and Accessibility New York, NY: Association for Computing Machinery, 2010:263–264. 10.1145/1878803.1878862.

101. Chu SL, Garcia B, Quance T, Geraci L, Woltering S, Quek F. Understanding storytelling as a design framework for cognitive support technologies for older adults. In: Proceedings of the International Symposium on Interactive Technology and Ageing Populations New York, NY: Association for Computing Machinery, 2016:24–33. 10.1145/2996267.2996270.

102. Lazar A, Thompson HJ, Piper AM, Demiris G. Rethinking the design of robotic pets for older adults. In: Proceedings of the 2016 ACM Conference on Designing Interactive Systems New York, NY: Association for Computing Machinery, 2016:1034–1046. 10.1145/2901790.2901811.

103. Demiris G, Oliver DP, Dickey G, Skubic M, Rantz M. Findings from a participatory evaluation of a smart home application for older adults. Technol Health Care. 2008;16(2):111–118. [PubMed: 18487857]

104. Vines J, Pritchard G, Wright P, Olivier P, Brittain K. An age-old problem: examining the discourses of ageing in HCI and strategies for future research. ACM Trans Comput Hum Interact. 2015;22(1):2 10.1145/2696867.

105. Frennert S, Östlund B.€ Review: Seven matters of concern of social robots and older people. Int J Soc Robot. 2014;6(2):299–310. 10.1007/s12369-013-0225-8.

106. Compagna D, Kohlbacher F. The limits of participatory technology development: the case of service robots in care facilities for older people. Technol Forecast Soc Change. 2015;93:19–31. 10.1016/j.techfore.2014.07.012.

107. Quinn SC. Ethics in public health research: protecting human subjects: the role of community advisory boards. Am J Public Health. 2004;94(6):918–922. 10.2105/AJPH.94.6.918. [PubMed: 15249289]

108. Lorenzen-Huber L, Boutain M, Camp LJ, Shankar K, Connelly KH. Privacy, technology, and aging: a proposed framework. Ageing Int. 2011;36(2):232–252. 10.1007/s12126-010-9083-y.

109. Vorrink SNW, Antonietti AMGEF, Kort HSM, Troosters T, Zanen P, Lammers J-WJ. Technology use by older adults in the Netherlands and its associations with demographics and health outcomes. Assistive Technol. 2016;29(4):188–196. 10.1080/10400435.2016.1219885.

110. Takemoto M, Lewars B, Hurst S, et al. Participants’ perceptions on the use of wearable devices to reduce sitting time: qualitative analysis.JMIR Mhealth Uhealth. 2018;6(3):e73 10.2196/mhealth.7857. [PubMed: 29599105]

111. Mitzner TL, Fausset CB, Boron JB, et al. Older adults’ training preferences for learning to use technology. Proc Hum Factors Ergon Soc Annu Meet. 2008;52(26):2047–2051. 10.1177/154193120805202603. [PubMed: 25309139]

112. Minatodani DE, Chao PJ, Berman SJ. Home telehealth: facilitators, barriers, and impact of nurse support among high-risk dialysis patients. Telemed J E Health. 2013;19(8):573–578. 10.1089/tmj.2012.0201. [PubMed: 23742629]

113. Taylor DM, Stone SD, Huijbregts MP. Remote participants’ experiences with a group-based stroke self-management program using videoconference technology. Rural Remote Health. 2012;12:1947. [PubMed: 22463728]

114. Collins LM, Nahum-Shani I, Almirall D. Optimization of behavioral dynamic treatment regimens based on the Sequential, Multiple Assignment, Randomized Trial (SMART). Clin Trials.2014;11(4):426–434. 10.1177/1740774514536795. [PubMed: 24902922]

115. Bellettiere J, Healy GN, LaMonte MJ, et al. Sedentary behavior and prevalent diabetes in 6,166 older women: the Objective Physical Activity and Cardiovascular Health Study. J Gerontol A Biol Sci Med Sci. In press. Online 5 3, 2018 10.1093/gerona/gly101.

116. LaCroix AZ, Rillamas-Sun E, Buchner D, et al. The Objective Physical Activity and Cardiovascular Disease Health in Older Women (OPACH) Study. BMC Public Health. 2017;17(1):192 10.1186/s12889-017-4065-6. [PubMed: 28193194]

117. Larson EB, Wang L, Bowen JD, et al. Exercise is associated withreduced risk for incident dementia among persons 65 years of age and older. Ann Intern Med. 2006;144(2):73–81. 10.7326/0003-4819-144-2-200601170-00004. [PubMed: 16418406]

Table 1.

Examples and Limitations of Using Technology for Measurement in Older Adults

Construct	Summary of current measurement techniques and limitations
Physical activity	Cut points for adults may not work in older adults; therefore, new cut points were developed in a laboratory setting.[13] However, these accelerometer-based cutoffs may not capture all meaningful behaviors and may misclassify the activity level of functionally impaired older adults with slow walking speed.[24] There are new machine-learned walking algorithms that were developed and validated in free-living older women.[25] Additional hip and wrist accelerometer algorithms are available.[26]
Posture/sitting	Thigh-worn activPALs are valid for posture in all age groups, but older adults' skin may be more sensitive and thigh-worn devices could be challenging in the long term. New machine-learned sitting algorithms have been developed and validated for older women but must be tested in other populations.[25]
Gait, balance, frailty, or mobility	For inertial devices (accelerometers, gyroscopes, and magnetometers), the most common placement locations are the lower back, shank, thigh, head, and trunk; whereas for force sensors, the location is typically the plantar surface of the foot. In-home monitoring allows for long-term monitoring of gait speed.[27] There is not currently a clinically sensitive technology to use in clinical care settings that quantifies relevant gait parameters to indicate frailty status.[28] Future research needs to enhance dynamic balance and gait control, which is more generalizable to everyday tasks than static balance.
Falls	Sensors for fall prevention are typically located on the lower back.[29] Europe is developing a human-centered design platform called the WIISEL for assessing fall risk in older adults.[30] It will allow researchers to quantify activity and assess the quality of gait under real-life conditions and enable clinicians to evaluate and monitor fall risk in elderly patients. The sensors within shoe insoles provide constant recording, but it is unclear who receives the feedback from the continuous monitoring. Danielsen et al.[29] proposed a prospective and contextaware fall-risk awareness protocol that uses sensors to capture expected chance of fall risk and alert health professionals, caregivers, and patients. Feedback should be associated with a risk of falling rather than simply identifying prospective fall risk. Apps can support interactions between clinicians and patients. Context assessment needs to consider more than the current situation but also evaluate how performance of activities evolves in the long term to identify trends for fall risk assessment.[29]
Life space	Passively measured GPS is promising, but there are issues related to battery life and participants' privacy concerns in having their locations revealed. Studies exploring life space typically occur in patient populations (i.e., Parkinson disease, dementia), and more research is needed in healthy aging populations.[31,32] Combining GPS and accelerometer data allows researchers to calculate number of pedestrian or vehicle trips to further explore the relationship between life space mobility and health.[23]
Eating and hydration	Image capture via wearables and smartphones documents intake; however, prompting participants to wear the wearable can be challenging. Additionally, battery life on the devices can limit the completeness of data collection. Lightweight wearables including cameras take pictures automatically, resulting in images that create a daily log of intake, offer an approach to capturing intake that may overcome many of the challenges older adults face with dietary intake reporting. Pictures capture times and frequency of meal consumption and could be useful memory joggers as well as valuable information for determining if an intervention needs to be provided.[33] Novel Assessment of Nutrition and Ageing (NANA)[8] uses tablets with touchscreens and webcams. It is designed to look holistically at nutrition and health by taking measures of diet, mood, cognition, and physical function. Future research should assess the effects of long-term use of technology in older adults and its impact on health behaviors.[34]

GPS, global positioning system; WIISEL, Wireless Sensor Insole for Collecting Gait Data.

Table 2.

Examples and Limitations of Using Technology for Interventions in Older Adults

Construct	Summary of current intervention techniques and limitations
Physical activity	Telephone delivery, web-based programs, smartphone applications, and virtual advisors can implement behavioral strategies from face-to-face interventions.[35] Limited research has tested these approaches in older adults. Previous studies used feedback from participants to develop and test different phone apps and smartphone platforms for intervention delivery.[36,37] Text messaging interventions increased PA in older adults.[38] Furthermore, in a recent review of the literature, seven of eight in-home telephone-based interventions showed improvement in older adults, four of four home-based pedometer/accelerometer-based interventions provided evidence of effectiveness, and two of four web-based intervention studies showed effectiveness.[39] In inactive older adults, a 3-month web-based PA intervention, which delivered monitoring and feedback by accelerometry and digital coaching, effectively increased PA and improved metabolic health.[37] Studies using mHealth with minimal behavioral support are not as effective as those interventions that integrate mHealth with multiple behavioral change techniques; however, evidence from larger RCTs with older adults is needed.[40]
Posture/ sitting	Several published pilot studies in older adults effectively reduced sitting time and used activPAL-derived feedback, with several larger RCTs underway including wearables and phone counseling.[6,16–20] Jawbone UP is easy to use for older adults, and regular vibrations remind individuals to break up their sitting.[41] Consumer wearables do not detect sitting accurately, as these devices focus on movement rather than posture.[42,43] The activPAL device does not yet provide real-time feedback. Some apps are available (e.g., Rise & Recharge) but do not specifically target older adults.
Gait, balance, frailty, or mobility	Balance and gait can be improved using body motion sensors and virtual sensory feedback in adults with stroke, Parkinson disease, multiple sclerosis, and cerebral palsy and in those with age-related gait deficits.[44] Various mHealth devices provide immediate biofeedback in visual, auditory, vibrotactile, or electrotactile formats. Previous research using motion capture with auditory biofeedback (using plantar force sensors) found an improvement in gait symmetry, speed, and balance in stroke survivors.[45] Additionally, wearable sensors can improve static balance, dynamic balance, or both immediately after intervention or on follow-up.[46] A tablet-based strength—balance training program that allowed monitoring of and assistance to autonomous-living older adults was more effective in improving gait and physical performance compared to a brochure-based program.[47] Future studies need to assess gait during single tasks as well as dual-task conditions, specifically including both arithmetic and verbal fluency tasks, to fully measure gait characteristics as related to frailty. Furthermore, previous RCTs included older adult samples with balance disorders (Parkinson disease, diabetes with peripheral neuropathy, stroke)[46]; therefore, future RCTs need to include healthy older adults to further evaluate interventions targeting balance, gait, and mobility.
Falls	Previous research used virtual reality to increase physical activity and reduce falls risk[48,49] (Wii and Kinetics games[50]). Intervention types mostly focus on reducing functional ability deficits, improving balance, and bolstering cognitive function to prevent falls. Participants may like using video games because of the immediate feedback and stimulating environment. Using video games at home can also reach a larger sector of the older populations (those who cannot go to medical centers to receive treatment). Few interventions have used smartphone apps to prevent falls, even though smartphones may be more popular than video consoles within the older adult population. The majority of pre-fall prevention interventions employ 3D technology and games to bolster evidence-based exercises focusing on intrinsic fall risk factors (i.e., functional ability deficits and balance impairments). Most are deployed within the home to increase adherence and reduce traveling costs.
Life space	Passively measured GPS is promising, but there are issues related to battery life and participants' privacy concerns in having their locations revealed. Few interventions have explored using these methods to improve life space mobility, but feasibility studies show that older adults are amenable to using devices. [21,22,27,51,52]
Eating and hydration	Interventions using technology to improve dietary intake and hydration are expanding. For hydration, watches will beep or signal fluid intake at intervals optimal for older adults based on age and physical condition. Another app enables shoppers to scan the barcode of food they intend to purchase or eat and receive immediate feedback regarding sodium levels, including suggestions for lower-sodium alternatives. Alternatively, logging food using spoken language utterances could be an easy way for older adults to keep track of food intake instead of relying on their memories. This utterance via the spoken language voice recording could be linked to food databases, and nutrient intakes could be calculated. A number of barriers specific to older adults make these types of interventions more challenging. For example, dementia, diminishing taste and smell, altered living conditions, or not having caregiver assistance make both dietary intake and collection of accurate information challenging for interventions targeting healthy eating.

PA, physical activity.