THE GERONTOLOGICAL SOCIETY OF AMERICA®

Journals of Gerontology: Medical Sciences
cite as: *J Gerontol A Biol Sci Med Sci*, 2021, Vol. 76, No. 11, 1981–1987
doi:10.1093/gerona/glab106
Advance Access publication April 9, 2021

OXFORD

Research Article

Free-Living Standing Activity as Assessed by Seismic Accelerometers and Cognitive Function in Community-Dwelling Older Adults: The MIND Trial

Shannon Halloway, PhD, RN,[1,*,†] Klodian Dhana, MD, PhD,[2,3,†] Pankaja Desai, PhD, MPH, MSW,[2,3] Puja Agarwal, PhD,[3,4] Thomas Holland, MD, MS,[2,3] Neelum T. Aggarwal, MD,[4,5] Jordi Evers, MSc,[6] Frank M. Sacks, MD,[7] Vincent J. Carey, PhD,[8] and Lisa L. Barnes, PhD[4,5]

[1]Rush University College of Nursing, Rush University Medical Center, Chicago, Illinois, USA. [2]Rush Institute for Healthy Aging, Rush University Medical Center, Chicago, Illinois, USA. [3]Department of Internal Medicine, Rush University Medical Center, Chicago, Illinois, USA. [4]Rush Alzheimer's Disease Center, Rush University Medical Center, Chicago, Illinois, USA. [5]Department of Neurological Sciences, Rush University Medical Center, Chicago, Illinois, USA. [6]McRoberts BV, The Hague, The Netherlands. [7]Department of Nutrition, Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA. [8]Channing Division of Network Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts, USA.

*Address correspondence to: Shannon Halloway, PhD, Rush University College of Nursing, 600 South Paulina, Suite 1080, Chicago, IL 60612, USA. E-mail: Shannon_Halloway@rush.edu

[†]These authors contributed equally to this work

Received: December 1, 2020; Editorial Decision Date: March 28, 2021

Decision Editor: Anne B. Newman, MD, MPH, FGSA

Abstract

Background: Few older adults are able to achieve recommended levels of moderate–vigorous physical activity despite known cognitive benefits. Alternatively, less intense activities such as standing can be easily integrated into daily life. No existing study has examined the impact of free-living standing activity during daily life as measured by a device on cognition in older adults. Our purpose was to examine the association between free-living standing activity and cognitive function in cognitively healthy older adults.
Method: Participants were 98 adults aged 65 years or older from the ongoing MIND trial (NCT02817074) without diagnoses or symptoms of mild cognitive impairment or dementia. Linear regression analyses tested cross-sectional associations between standing activity (duration and intensity from the MoveMonitor+ accelerometer/gyroscope) and cognition (4 cognitive domains constructed from 12 cognitive performance tests).
Results: Participants were on average 69.7 years old (SD = 3.7), 69.4% women, and 73.5% had a college degree or higher. Higher mean intensity of standing activity was significantly associated with higher levels of perceptual speed when adjusting for age, gender, and education level. Each log unit increase in standing activity intensity was associated with 0.72 units higher of perceptual speed (p = .023). When we additionally adjusted for cognitive activities and moderate–vigorous physical activity, and then also for body mass index, depressive symptoms, prescription medication use, and device wear time, the positive association remained.
Conclusions: These findings should be further explored in longitudinal analyses and interventions for cognition that incorporate small changes to free-living activity in addition to promoting moderate–vigorous physical activity.

Keywords: Cognition, Cognitive aging, Physical activity, Standing

The benefits of moderate–vigorous physical activity in older adults are well known (1,2), including enhancing cognitive health, particularly better performance in memory and executive function (3). However, few older adults achieve the recommended levels of moderate–vigorous physical activity (ie, 150 minutes of moderate–vigorous physical activity per week in the United States) that are needed for optimal cognitive health (4,5). There are several barriers to achieving these recommended levels of physical activity in older adults, most frequently limitations due to physical function and overall health (6,7). However, smaller changes to daily activity can yield some cognitive benefits, and smaller changes are easier for older adults to achieve, more acceptable, and more sustainable over long periods of time (8,9). For instance, light-intensity physical activity, or movement activities between 1.5 and 3 metabolic equivalents (METs), is associated with better cognitive function (10–12), though findings across studies are mixed (13). Unfortunately, some older adults still struggle to achieve levels of light-intensity physical activity that are associated with better health outcomes (14).

An example of an even smaller change to daily activity is time spent standing, which can easily be integrated into daily routines by older adults. Standing interrupts sedentary behavior, that is, activities completed while sitting, reclining, or lying down with METs of 1.5 or less (15). In large amounts, sedentary behavior, particularly uninterrupted sedentary behavior, is independently associated with poor health outcomes (16,17), such as decreased brain volumes and worsened cognitive function (18) including processing speed (ie, perceptual speed; ability to perceive and process information rapidly) (19). Standing activity involves both the duration and intensity of activities completed while in a standing, erect position, but does not involve active acceleration like light– or moderate–vigorous physical activity (20–22). In contrast to sedentary behavior, standing activity requires balance and strength in order to maintain the standing posture (23,24). Although less physically demanding than light– or moderate–vigorous physical activity, standing may still have important cognitive implications in older adults (25).

Laboratory biomechanical studies that used performance-based tests, balance boards, or multiple wearable devices to assess standing activity have shown that some standing measures (ie, postural stability and motor planning) are positively associated with global measures of cognitive function (26–28). For example, in a systematic review of studies with adults with Alzheimer's disease dementia, performance and device measures of postural stability were positively associated with severity of general cognitive impairment (26), similar to findings with patients with chronic kidney disease where poor posture stability was associated with worsened general cognitive function (27). Likewise, there was greater error in device-assessed motor planning when standing in older adults with cognitive impairment compared to cognitively normal older adults (28). Such laboratory-based measures of standing capture performance and function in highly controlled settings for brief period of times, which may not accurately represent typical daily activity or function. This is in contrast to free-living activity, which is defined as activity completed throughout daily life in natural conditions, including community settings (29,30). Additionally, these laboratory-based studies of standing activity did not utilize a battery of neurocognitive tests to obtain information on specific cognitive domains.

In order to accurately assess free-living standing activity (including standing activity duration and intensity) in a community setting, specific devices that can capture both minute variations in postural changes and accelerations must be utilized (21,22,31). Unlike the more commonly used piezoelectric accelerometers that detect accelerations only (5,32), novel combination devices, such as a seismic accelerometer combined with a triaxial gyroscope, can capture inclination and posture information even during static activity when the individual is not dynamically accelerating (ie, walking, jogging, ambulation) (33). However, no existing study of cognitive function has utilized a device measure of free-living standing activity in the community setting. Thus, the purpose of this analysis is to examine the association between standing activity (duration and intensity as measured by a combined seismic accelerometer and triaxial gyroscope) and cognitive function (global cognitive function and specific cognitive domains) in cognitively healthy older adults. We hypothesize significant associations will be present between standing activity and global cognitive function, with changes in memory, executive function, and perceptual speed, consistent with existing physical activity and cognitive function literature (3,19).

Method

This is a secondary analysis of data from the MIND (Mediterranean-Dash intervention for Neurodegenderative Delay) trial (NCT02817074), an ongoing study that tests the effects of a 3-year diet intervention on cognitive decline in older adults who are cognitively unimpaired, but at greater risk for Alzheimer's disease due to family history (34). Data collection began in 2016 in the Chicago and Boston metropolitan areas. The MoveMonitor+ ancillary study recruited existing MIND trial participants from the Chicago site to wear the MoveMonitor+, starting at the baseline data collection time point. The MoveMonitor+ is a small portable device that combines a seismic accelerometer and a triaxial gyroscope and that assesses a wide range of activity behaviors. In this secondary analysis, we used cross-sectional data from the baseline time point of the MIND trial.

Participants

The parent MIND trial participants include 604 community-dwelling adults 65–84 years of age, either living in the Boston (n = 302) or Chicago (n = 302) metropolitan areas. At the time of analysis, the MoveMonitor+ ancillary study enrolled 98 participants at the baseline visit from the Chicago site. All participants provided written informed consent for data collection and participation in the parent trial and ancillary study. The study was approved by the Rush University Medical Center Institutional Review Board, and a waiver of consent was obtained for the current data analysis. The parent trial targets older adults who were at risk for dementia but without current cognitive impairment, have a family history of dementia, are overweight or obese, and have a suboptimal diet as defined below.

Inclusion criteria for the parent trial included that participants had to (a) be 65–84 years of age; (b) have a body mass index (BMI) of 25 kg/m^2 or greater; (c) self-report a first-degree family history of dementia; (d) have no mild cognitive impairment or dementia (a score of 22 or greater on the Montreal Cognitive Assessment; (35)); and (e) have a suboptimal diet (defined as a score of ≤8 out of 14 on the MIND Diet, which includes frequency of eating from 10 brain-healthy food groups and 5 unhealthy food groups (36–38)). Exclusion criteria included (a) having allergies to nuts, berries, olive oil, or fish; (b) having psychosis or bipolar disorder; (c) engaging in alcohol or substance abuse within the past 6 months; (d) having unstable or recent onset of cardiovascular disease, including a stroke; (e) receiving a diagnosis of cancer within the past 5 years; (f) having gastrointestinal conditions associated with weight change (eg, colostomy or gastric bypass surgery); (g) having a history of brain injury;

(h) having a history of liver disease or Hepatitis C; and (i) taking medications for Alzheimer's disease or Parkinson's disease.

Measures

MoveMonitor+ seismic accelerometer

The DynaPort MoveMonitor+ (McRoberts BV) is a seismic accelerometer and triaxial gyroscope device that provides valid and reliable measures of all intensities of physical activity, movements, and postures including standing activity (21,22,31,33,39–42). The MoveMonitor+ offers several advantages over other device measures of activity. Unlike triaxial accelerometers, the MoveMonitor+ is sensitive to gravitational acceleration in both static and dynamic behaviors (33). Thus, the MoveMonitor+ is able to accurately capture postural changes and characteristics, providing valid and reliable data regarding activity in every posture, which is usually not available in a traditional triaxial accelerometer (21,33,43). The MoveMonitor+ is a slim monitor that is worn at the lower back at the waist level. Participants were instructed to wear the MoveMonitor+ for 7 consecutive days during all hours of the day, including sleeping, except while bathing, showering, or swimming. In order to be included in analyses, participants were required to wear the device for a minimum of 2 days for 10 hours each day, based on previously selected wear time requirements established for these measures in validation studies with diverse older adult populations (21,22,40,42,44,45). The raw MoveMonitor+ data are sent to the McRoberts BV secure, cloud-based platform and then analyzed. The McRoberts BV MoveMonitor+ algorithms classify all activities with a resolution of 1 second. The McRoberts BV database stores approximately 200 parameters per measurement, and the daily time interval was utilized for the present analyses.

Standing activity included mean daily minutes of standing activity duration and mean standing activity intensity (force during the standing posture). Standing activity variables did not include periods of walking, jogging, or other active ambulation. Intensity of physical activity was calculated based on accelerations detected by the MoveMonitor+. Moderate–vigorous physical activity (included as a covariate) was the mean daily number of minutes spent in activity above 3 METs. To correct for positively skewed data, all standing activity and physical activity variables were log-transformed.

Cognitive function

Cognitive function was assessed using a battery of 12 neurocognitive tests (34). The tests evaluated 4 cognitive domains: episodic memory—recall ability (Word List Memory, Word List Recall, Word List Recognition, East Boston Memory Test, East Boston Delayed Recall); semantic memory—accumulated long-term knowledge (Verbal Fluency, Multilingual Naming Test); executive functioning—ability to organize thoughts and activities (Trails B, Flanker Inhibitory Control); and perceptual speed—ability to quickly and accurately make comparison (Trails A, Pattern Comparison, Digit Symbol Substitution Test). Raw scores of all tests were converted to *z*-scores. Composite scores for each domain were calculated by averaging *z*-scores of the individual tests. Global cognition was calculated by averaging *z*-scores for the 4 domains.

Covariates

We included covariates that may confound the association between standing activity and cognitive function, including demographics, BMI, regular prescription medication use, cognitive activity, and total daily minutes of moderate–vigorous physical activity. Demographics included age, race, gender, and education. BMI (kg/m^2) was calculated using weight and height measurements that were assessed by a trained technician. Regular prescription medication use was measured by participants self-reporting any prescription medications taken regularly (yes or no to any prescription medications taken at least 5 days per month for chronic health problems, or prescription pain medications). Cognitive activity was assessed with a structured self-report questionnaire. The questionnaire assessed frequency and duration of 7 activities that involve information processing without physical or social demand: reading magazines, reading books, reading newspapers, writing letters, visiting a library, attending a play, and playing games (eg, chess, checkers, and cards). The item scores (range: 1–5) were averaged to calculate the cognitive activity composite score. In an epidemiological cohort study with community-dwelling older adults, higher cognitive activity scores were associated with slower cognitive decline (46). Total daily minutes of moderate–vigorous physical activity as assessed by the MoveMonitor+ and percent wear time of the MoveMonitor+ were also included as covariates.

Data Analysis

Baseline characteristics of the study population are shown as mean and *SD*, percentages of participants, or medians and quartiles. Statistical differences of baseline characteristics among individuals with and without accelerometer data were analyzed with the chi-squared test and Student's *t* test as appropriate.

Linear regression analyses were used to quantify the associations between standing activity (independent variables) with global cognition and cognitive domains, including executive functioning, perceptual speed, episodic memory, and semantic memory (outcomes/dependent variables). Measures of standing activity (as assessed by the MoveMonitor+ combined seismic accelerometer/triaxial gyroscope) included standing activity duration and standing activity intensity. The values of each of these measures were log-transformed to stabilize the variance and to obtain normal distribution variables. Three linear regression models were conducted. Model 1 was adjusted for age, gender, race, and education, and Model 2 was additionally adjusted for BMI category (25–29.9, 30–34.9, and >35 kg/m^2), medication use, late-life cognitive activities, and total daily minutes of moderate–vigorous physical activity. Model 2 was extended by adjusting for the percentage of the day that the MoveMonitor+ was worn (Model 3).

In the sensitivity analysis, further analyses were conducted to validate the robustness of the results. Associations between measures of standing activity, global cognition, and cognitive domains were investigated independently in individuals younger and older than 70 years old, in women and men, and in those with high (postgraduate) and lower levels of education.

Results

There were 98 participants with a mean age of 69.7 years (*SD* = 3.7). Of the 98 participants, 69% were women, 84.7% were White, and over 73.4% had received a college degree or higher (Supplementary Table 1). Participants reported low levels of depressive symptoms (median = <0.1 [interquartile range = 1]). Participants reported a score of 3.4 of 5 (*SD* = 0.6) on the measure of self-reported cognitive activities, which is comparable to an epidemiological cohort study of older adults of similar sociodemographic backgrounds (46), and engaged in nearly 14 minutes (*SD* = 1.4) of daily moderate–vigorous physical activity. Over 90% of participants wore the MoveMonitor+ for 6 days or more for a duration of 90% of the 24-hour day. There were no significant differences between participants from the MoveMonitor+ ancillary study and the remaining 204 participants from the Rush site that did not participate in the ancillary study. Log-transformed standing activity duration was generally correlated with log-transformed standing activity intensity (r = .25) and both standing activity variables were moderately correlated with moderate–vigorous physical activity (r = .34–.43).

First, we conducted linear regression analyses (Model 1) to test the associations between the 2 standing activity variables (standing activity duration, standing activity intensity) and cognitive function (global cognition, episodic memory, semantic memory, executive function, perceptual speed), controlling for demographics (age, gender, race, education; Table 1). These analyses indicated significant positive associations between standing activity intensity and perceptual speed. One log unit increase in standing activity intensity was associated with 0.77 unit higher in perceptual speed (β = 0.72, SE = 0.31, p = .023).

In Model 2, we additionally adjusted for BMI category (25–29.9, 30–34.9, and >35 kg/m^2), medication use, late-life cognitive activities, and daily moderate–vigorous physical activity. Significant associations between standing activity intensity and perceptual speed remained (β = 0.72, SE = 0.31, p = .021). These results did not vary in Model 3, where we further adjusted for the influence of the percent of time the MoveMonitor+ was worn (β = 0.68, SE = 0.33, p = .039).

Across all 3 models, there were no significant associations between standing activity duration and any cognitive function outcome. In sensitivity analyses, we found significant associations between standing activity intensity and perceptual speed in women (β = 0.84, SE = 0.34, p = .017) and in those with higher education (β = 1.77, SE = 0.85, p = .043). There were no significant interaction effects between demographic and standing activity variables.

Discussion

We tested the association of free-living standing activity (standing activity duration and standing activity intensity) as measured by a combination device with cognitive function (4 cognitive domains and global cognition) in community-dwelling older adults. When controlling for demographics, our findings indicated that greater standing activity intensity was significantly associated with higher levels of perceptual speed. This significant association was consistent across 2 additional models that additionally adjusted for BMI category, prescription medication use, late-life cognitive activity and daily moderate–vigorous physical activity, and then for percent wear time of the MoveMonitor+. It is important to note that only models with standing activity intensity were significant, so we may cautiously infer that, in contrast to increasing intensity while standing, simply standing for longer periods of times may not yield cognitive effects.

The findings obtained for perceptual speed may have meaningful lifestyle implications. Perceptual speed is vital for daily activities and tasks that require accuracy and speed (47), such as taking medications, fulfilling a grocery list, or handling money in busy stores, tasks which are crucial for maintaining independence with age. Perceptual speed also plays an important role in memory retrieval and can contribute to the slowing of memory retrieval that occurs with age (48) even when controlling for differences in visual acuity and general age-related slowing (49). Thus, perceptual speed should be optimized for successful aging. Nonetheless, implications regarding significant findings from this analysis must be made cautiously, given the lack of significant results across all cognitive domains, with no significant associations with standing activity duration.

This is the first study to examine standing activity intensity and cognitive function outcomes in a free-living, community context, which may be more representative of older adults' daily life. Yet, laboratory-based biomechanical studies may help provide context and have the advantage of relatively controlled environments, reducing variability characteristic of free-living settings. Specific standing-related factors (eg, balance, stability, coordination) assessed in a laboratory setting are directly related to the ability to maintain a standing posture, and better performance in these factors may lead to improved standing duration and intensity (20,23,50,51). However, such factors are vulnerable to age-related changes. Compared to younger adults, older adults experience significant declines in balance, postural stability, and coordination while standing, directly impacting standing activity intensity (52–54).

Evidence in older adult samples points to associations between important factors related to standing (eg, balance, stability, and

Table 1. Associations Between Standing Activity and Cognitive Function in 98 Community-Dwelling Older Adults From the MIND Trial

	Cognitive Function Outcomes														
	Episodic Memory			Semantic Memory			Executive Function			Perceptual Speed			Global Cognition		
Variable	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
Model 1[a]															
SA duration	0.08	0.16	.640	0.11	0.17	.512	−0.10	0.18	.597	<−0.01	0.16	.997	0.04	0.11	.751
SA intensity	−0.03	0.32	.919	−0.21	0.34	.541	0.50	0.35	.158	0.72	0.31	.023	0.22	0.21	.315
Model 2[b]															
SA duration	0.02	0.19	.418	0.20	0.18	.277	−0.16	0.21	.443	−0.09	0.18	.633	0.05	0.13	.700
SA intensity	−0.11	0.34	.754	−0.06	0.34	.868	0.59	0.40	.149	0.70	0.32	.034	0.30	0.24	.216
Model 3[c]															
SA duration	0.23	0.19	.238	0.18	0.19	.340	−0.06	0.22	.780	−0.04	0.19	.829	0.11	0.13	.413
SA intensity	−0.13	0.34	.704	−0.05	0.34	.896	0.50	0.38	.184	0.68	0.33	.039	0.20	0.23	.394

Notes: SA = standing activity.

[a]Adjusted for age, gender, race, and education. [b]Adjusted for age, gender, race, education, cognitive activities, and moderate–vigorous physical activity. [c]Adjusted for age, gender, race, education, body mass index category (25–29.9, 30–34.9, and >35), regular prescription medication use (yes/no), depressive symptoms, cognitive activities, moderate–vigorous physical activity, and MoveMonitor+ wear time.

coordination) and cognitive function. Better performance in standing-related factors (eg, balance, coordination, motor planning while standing, stability in the standing posture) was related to higher general cognition scores (27,28). However, in our analyses, we found significant associations only between standing activity intensity and the cognitive domain of perceptual speed. A meta-analysis of cross-sectional studies of balance and coordination also yielded significant associations in perceptual speed (55), similar to findings from an intervention trial testing standing exercises for balance and coordination that also found benefits to perceptual speed (56). In sum, important factors related to free-living standing activity intensity, such as balance and coordination, may also be related to perceptual speed.

A major strength of our study was the assessment of free-living standing activity throughout daily life in the community setting using a combination device, with high levels of wear time. This is in contrast to the earlier biomechanical studies that capture specific functions or tasks in highly controlled laboratory settings for brief periods of time. By assessing total daily activities, we may be able to identify realistic opportunities for behavior change that may be used to develop lifestyle interventions. One way to augment standing activity intensity is to complete other activities while maintaining a standing posture. To our knowledge, existing studies have not deliberately tested the influence of participating in lifestyle activities while standing (eg, sorting mail, cooking), which may increase standing activity intensity. Dual-task activities, which involve completing 2 tasks concurrently, particularly a motor activity paired with a cognitive activity (eg, completing a puzzle while standing) (57), have shown promising benefits to motor coordination and cognitive function (58). However, it is unclear if dual-task activities simultaneously enhance standing activity intensity, which should be clarified in future work.

We must note the limitations of this secondary analysis. First, this analysis utilized cross-sectional data, so neither directionality nor causality can be established. It is possible that those with better perceptual speed may be more likely to participate in standing activities, with greater standing intensity. Moreover, there were no significant associations with standing activity duration, so all implications must be made with caution. Second, although the MoveMonitor+ provides comprehensive and accurate data regarding standing activity duration and intensity, the MoveMonitor+ does not specify other activity types participants may engage in while standing (eg, crafts, reading, cooking). There is also no heat sensor or heart rate component that could provide precise information about device removal; thus, time spent on activities while the device was not worn may be calculated as inactivity instead. Third, our sample was comprised of participants from an existing trial who were disproportionately women and White and had an education level that is significantly higher than the average level in the United States. Moreover, older adults were excluded for presence of major health problems and chronic conditions were assessed by self-report only. These limitations impact our ability to generalize findings to a broader population, particularly those with lower levels of education. Additionally, this subsample represented volunteers who participated in this particular ancillary study, which may further diminish generalizability.

To our knowledge, no other study examining cognitive function has assessed free-living standing activity, which reflects participants' daily life in community settings away from the highly controlled laboratory. Our findings on free-living standing activity and perceptual speed should be further investigated in longitudinal analyses to further elucidate associations and establish directionality. There is potential for standing activity intensity to be incorporated in lifestyle-based interventions. This is crucial because of older adults' preference for lifestyle-based activities that involve small changes to daily life instead of highly prescriptive and structured exercise sessions, which often take place in a laboratory or gym setting (8,9,59). Although existing evidence certainly supports highly structured exercise sessions for cognitive function and brain health in older adults (60,61), such interventions may not be attainable or realistic for all older adult populations, particularly those with chronic health problems or functional limitations (59). Thus, researchers should consider future investigation on integrating standing activity intensity throughout everyday life and the potential benefits to cognitive function.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

Funding

This work was supported by the National Institutes of Health (R01 AG051641, 1R01AG052583-01) and the Consolidated Anti-Aging Foundation.

Conflict of Interest

None declared.

Acknowledgments

We would like to acknowledge the life and career of Dr. Martha Clare Morris. We also would like to thank Yamin Wang for her data management support.

Author Contributions

Study conception: S.H.; study design: S.H. and K.D.; protocol and methods: S.H., T.H., N.T.A., J.E., and F.M.S.; analysis: K.D.; interpretation of results: S.H., K.D., P.D., P.A., J.E., F.M.S., V.J.C., and L.L.B.; draft manuscript preparation: S.H. All authors reviewed the results, provided critique on manuscript drafts, and approved the final version of the manuscript.

References

1. Benjamin EJ, Muntner P, Alonso A, et al. Heart disease and stroke statistics—2019 update: a report from the American Heart Association. *Circulation*. 2019;139(10):e56–e528. doi:10.1161/CIR.0000000000000659.
2. Gorelick PB, Furie KL, Iadecola C, et al.; American Heart Association/American Stroke Association. Defining optimal brain health in adults: a presidential advisory from the American Heart Association/American Stroke Association. *Stroke*. 2017;48(10):e284–e303. doi10.1161/STR.0000000000000148
3. Engeroff T, Ingmann T, Banzer W. Physical activity throughout the adult life span and domain-specific cognitive function in old age: a systematic review of cross-sectional and longitudinal data. *Sports Med*. 2018;48(6)::1405–1436. doi:10.1007/s40279-018-0920-6
4. Department of Health and Human Services. *Physical Activity Guidelines for Americans*. 2nd ed. Washington, D.C.: U.S. Department of Health and Human Services; 2018.
5. Evenson KR, Buchner DM, Morland KB. Objective measurement of physical activity and sedentary behavior among US adults aged 60 years or older. *Prev Chronic Dis*. 2012;9:E26. doi:10.5888/pcd9.110109

6. Centers for Disease Control and Prevention. *Strategies to Prevent Obesity and Other Chronic Diseases: The CDC Guide to Strategies to Increase Physical Activity in the Community*. Atlanta, GA: U.S. Department and Human Services; 2011.
7. Murtagh EM, Nichols L, Mohammed MA, Holder R, Nevill AM, Murphy MH. The effect of walking on risk factors for cardiovascular disease: an updated systematic review and meta-analysis of randomised control trials. *Prevent. Med*. 2015;72(suppl. C):34–43. doi:10.1016/j.ypmed.2014.12.041
8. Amireault S, Baier JM, Spencer JR. Physical activity preferences among older adults: a systematic review. *J Aging Phys Act*. 2018;1–12. doi:10.1123/japa.2017-0234
9. Dunn AL, Buller DB, Dearing JW, et al. Adopting an evidence-based lifestyle physical activity program: dissemination study design and methods. *Transl Behav Med*. 2012;2(2):199–208. doi:10.1007/s13142-011-0063-x
10. Stubbs B, Chen LJ, Chang CY, Sun WJ, Ku PW. Accelerometer-assessed light physical activity is protective of future cognitive ability: a longitudinal study among community dwelling older adults. *Exp Gerontol*. 2017;91:104–109. doi:10.1016/j.exger.2017.03.003
11. Johnson LG, Butson ML, Polman RC, et al. Light physical activity is positively associated with cognitive performance in older community dwelling adults. *J Sci Med Sport*. 2016;19(11):877–882. doi:10.1016/j.jsams.2016.02.002.
12. Lee S, Yuki A, Nishita Y, et al. Research relationship between light-intensity physical activity and cognitive function in a community-dwelling elderly population-an 8-year longitudinal study. *J Am Geriatr Soc*. 2013;61(3):452–453. doi:10.1111/jgs.12119
13. Zhu W, Wadley VG, Howard VJ, Hutto B, Blair SN, Hooker SP. Objectively measured physical activity and cognitive function in older adults. *Med Sci Sports Exerc*. 2017;49(1):47–53. doi:10.1249/MSS.0000000000001079
14. Loprinzi PD, Lee H, Cardinal BJ. Evidence to support including lifestyle light-intensity recommendations in physical activity guidelines for older adults. *Am J Health Promot*. 2015;29(5):277–284. doi:10.4278/ajhp.130709-QUAN-354
15. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN)—terminology consensus project process and outcome. *Int J Behav Nutr Phys Act*. 2017;14:75. doi:10.1186/s12966-017-0525-8
16. Chase JM, Lockhart CK, Ashe MC, Madden KM. Accelerometer-based measures of sedentary behavior and cardio-metabolic risk in active older adults. *Clin Invest Med*. 2014;37(2):E108–E116. doi:10.25011/cim.v37i2.21093
17. Halloway S, Wilbur J, Schoeny ME, Semanik PA, Marquez DX. Combined effects of sedentary behavior and moderate-to-vigorous physical activity on cardiovascular health in older, community-dwelling Latinos. *J Aging Phys Act*. 2016;24(2):296–304. doi:10.1123/japa.2015-0096
18. Klaren RE, Hubbard EA, Wetter NC, Sutton BP, Motl RW. Objectively measured sedentary behavior and brain volumetric measurements in multiple sclerosis. *Neurodegener Dis Manag*. 2017;7(1):31–37. doi:10.2217/nmt-2016-0036
19. Wanigatunga AA, Manini TM, Cook DR, et al. Community-based activity and sedentary patterns are associated with cognitive performance in mobility-limited older adults. *Front Aging Neurosci*. 2018;10:341. doi:10.3389/fnagi.2018.00341
20. Alqahtani BA, Ferchak MA, Huppert TJ, et al. Standing balance and strength measurements in older adults living in residential care communities. *Aging Clin Exp Res*. 2017;29(5):1021–1030. doi:10.1007/s40520-016-0693-4
21. de Groot S, Nieuwenhuizen MG. Validity and reliability of measuring activities, movement intensity and energy expenditure with the DynaPort MoveMonitor. *Med Eng Phys*. 2013;35(10):1499–1505. doi:10.1016/j.medengphy.2013.04.004
22. Van Hees VT, Slootmaker SM, De Groot G, Van Mechelen W, Van Lummel RC. Reproducibility of a triaxial seismic accelerometer (DynaPort). *Med Sci Sports Exerc*. 2009;41(4):810–817. doi:10.1249/MSS.0b013e31818ff636
23. Cohen RG, Baer JL, Ravichandra R, Kral D, McGowan C, Cacciatore TW. Lighten up! Postural instructions affect static and dynamic balance in healthy older adults. *Innov Aging*. 2020;4(2):igz056. doi:10.1093/geroni/igz056
24. Edwardson CL, Rowlands AV, Bunnewell S, et al. Accuracy of posture allocation algorithms for thigh- and waist-worn accelerometers. *Med Sci Sports Exerc*. 2016;48(6):1085–1090. doi:10.1249/MSS.0000000000000865
25. Duvivier BMFM, Schaper NC, Koster A, et al. Benefits of substituting sitting with standing and walking in free-living conditions for cardiometabolic risk markers, cognition and mood in overweight adults. *Front Physiol*. 2017;8:353. doi:10.3389/fphys.2017.00353
26. Mesbah N, Perry M, Hill KD, Kaur M, Hale L. Postural stability in older adults with Alzheimer disease. *Phys Ther*. 2017;97(3):290–309. doi:10.2522/ptj.20160115
27. Wilkinson TJ, Nixon DGD, Smith AC. Postural stability during standing and its association with physical and cognitive functions in non-dialysis chronic kidney disease patients. *Int Urol Nephrol*. 2019;51(8):1407–1414. doi:10.1007/s11255-019-02192-4
28. Zhou H, Lee H, Lee J, Schwenk M, Najafi B. Motor planning error: toward measuring cognitive frailty in older adults using wearables. *Sensors (Basel)*. 2018;18(3). doi:10.3390/s18030926
29. Chapman JJ, Roberts JA, Nguyen VT, Breakspear M. Quantification of free-living activity patterns using accelerometry in adults with mental illness. *Sci Rep*. 2017;7(1):43174. doi:10.1038/srep43174
30. Lee K, Kwan M-P. Physical activity classification in free-living conditions using smartphone accelerometer data and exploration of predicted results. *Comput Environ Urban Syst*. 2018;67:124–131. doi:10.1016/j.compenvurbsys.2017.09.012
31. van Schooten KS, van Dieen JH, Pijnappels M, et al. The association between age and accelerometry-derived types of habitual daily activity: an observational study over the adult life span in the Netherlands. *BMC Public Health*. 2018;18(1):824. doi:10.1186/s12889-018-5719-8
32. Copeland JL, Ashe MC, Biddle SJ, et al. Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. *Br J Sports Med*. 2017;51(21):1539. doi:10.1136/bjsports-2016-097210
33. van Hees VT, van Lummel RC, Westerterp KR. Estimating activity-related energy expenditure under sedentary conditions using a tri-axial seismic accelerometer. *Obesity (Silver Spring)*. 2009;17(6):1287–1292. doi:10.1038/oby.2009.55
34. Liu X, Morris MC, Dhana K, et al. Mediterranean-DASH Intervention for Neurodegenerative Delay (MIND) study: rationale, design and baseline characteristics of a randomized control trial of the MIND diet on cognitive decline. *Contemp Clin Trials*. 2021;102:106270. doi:10.1016/j.cct.2021.106270
35. Nasreddine ZS, Phillips NA, Bédirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *J Am Geriatr Soc*. 2005;53(4):695–699. doi:10.1111/j.1532-5415.2005.53221.x
36. Morris MC, Tangney CC, Wang Y, et al. MIND diet slows cognitive decline with aging. *Alzheimers Dement*. 2015;11(9):1015–1022. doi:10.1016/j.jalz.2015.04.011
37. Morris MC. Nutrition and risk of dementia: overview and methodological issues. *Ann NY Acad Sci* 2016;1367:31–7. doi:10.1111/nyas.13047
38. Morris MC, Tangney CC, Wang Y, Sacks FM, Bennett DA, Aggarwal NT. MIND diet associated with reduced incidence of Alzheimer's disease. *Alzheimers Dement*. 2015;11(9):1007–1014. doi:10.1016/j.jalz.2014.11.009
39. Sasaki JE, Hickey AM, Staudenmayer JW, John D, Kent JA, Freedson PS. Performance of activity classification algorithms in free-living older adults. *Med Sci Sports Exerc*. 2016;48(5):941–950. doi:10.1249/MSS.0000000000000844
40. Taylor LM, Klenk J, Maney AJ, Kerse N, Macdonald BM, Maddison R. Validation of a body-worn accelerometer to measure activity patterns in octogenarians. *Arch Phys Med Rehabil*. 2014;95(5):930–934. doi:10.1016/j.apmr.2014.01.013
41. van Lummel RC, Walgaard S, Pijnappels M, et al. Physical performance and physical activity in older adults: associated but separate domains of physical function in old age. *PLoS ONE*. 2015;10(12):e0144048. doi:10.1371/journal.pone.0144048
42. van Schooten KS, Rispens SM, Elders PJ, Lips P, van Dieën JH, Pijnappels M. Assessing physical activity in older adults: required days of

trunk accelerometer measurements for reliable estimation. *J Aging Phys Act.* 2015;23(1):9–17. doi:10.1123/japa.2013-0103

43. Tedesco S, Barton J, O'Flynn B. A review of activity trackers for senior citizens: research perspectives, commercial landscape and the role of the insurance industry. *Sensors (Basel).* 2017;17(6):1277. doi:10.3390/s17061277
44. Langer D, Gosselink R, Sena R, Burtin C, Decramer M, Troosters T. Validation of two activity monitors in patients with COPD. *Thorax.* 2009;64(7):641–642. doi:10.1136/thx.2008.112102
45. Storm FA, Heller BW, Mazzà C. Step detection and activity recognition accuracy of seven physical activity monitors. *PLoS ONE.* 2015;10(3):e0118723. doi:10.1371/journal.pone.0118723
46. Wilson RS, Segawa E, Boyle PA, Bennett DA. Influence of late-life cognitive activity on cognitive health. *Neurology.* 2012;78(15):1123–1129. doi:10.1212/WNL.0b013e31824f8c03
47. Ackerman PL, Beier ME. Further explorations of perceptual speed abilities in the context of assessment methods, cognitive abilities, and individual differences during skill acquisition. *J Exp Psychol Appl.* 2007;13(4):249–272. doi:10.1037/1076-898X.13.4.249
48. Bucur B, Madden DJ, Spaniol J, et al. Age-related slowing of memory retrieval: contributions of perceptual speed and cerebral white matter integrity. *Neurobiol Aging.* 2008;29(7):1070–1079. doi:10.1016/j.neurobiolaging.2007.02.008
49. McCabe J, Hartman M. An analysis of age differences in perceptual speed. *Mem Cognit.* 2008;36(8):1495–1508. doi:10.3758/MC.36.8.1495
50. Bauman AE, Sallis JF, Dzewaltowski DA, Owen N. Toward a better understanding of the influences on physical activity: the role of determinants, correlates, causal variables, mediators, moderators, and confounders. *Am J Prev Med.* 2002;23(suppl. 2):5–14. doi:10.1016/s0749-3797(02)00469-5
51. Kang HG, Lipsitz LA. Stiffness control of balance during quiet standing and dual task in older adults: the MOBILIZE Boston Study. *J Neurophysiol.* 2010;104(6):3510–3517. doi:10.1152/jn.00820.2009
52. Fuchioka S, Iwata A, Higuchi Y, Miyake M, Kanda S, Nishiyama T. The forward velocity of the center of pressure in the midfoot is a major predictor of gait speed in older adults. *Int J Gerontol.* 2015;9(2):119–122. doi:10.1016/j.ijge.2015.05.010
53. Hagedorn TJ, Dufour AB, Golightly YM, et al. Factors affecting center of pressure in older adults: the Framingham Foot Study. *J Foot Ankle Res.* 2013;6(1):18. doi:10.1186/1757-1146-6-18
54. Tesio L, Rota V. The motion of body center of mass during walking: a review oriented to clinical applications. *Front Neurol.* 2019;10:999. doi:10.3389/fneur.2019.00999
55. Demnitz N, Esser P, Dawes H, et al. A systematic review and meta-analysis of cross-sectional studies examining the relationship between mobility and cognition in healthy older adults. *Gait Posture.* 2016;50:164–174. doi:10.1016/j.gaitpost.2016.08.028
56. Voelcker-Rehage C, Godde B, Staudinger UM. Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. *Front Hum Neurosci.* 2011;5:26. doi:10.3389/fnhum.2011.00026
57. Hofheinz M, Mibs M, Elsner B. Dual task training for improving balance and gait in people with stroke. *Cochrane Database Syst Rev.* 2016(10):CD012403. doi:10.1002/14651858.CD012403
58. Wollesen B, Voelcker-Rehage C. Training effects on motor–cognitive dual-task performance in older adults. *Eur Rev Aging Phys Act.* 2014;11(1):5–24. doi:10.1007/s11556-013-0122-z
59. Darden D, Richardson C, Jackson EA. Physical activity and exercise for secondary prevention among patients with cardiovascular disease. *Curr Cardiovasc Risk Rep.* 2013;7(6). doi:10.1007/s12170-013-0354-5
60. Brasure M, Desai P, Davila H, et al. Physical activity interventions in preventing cognitive decline and Alzheimer-type dementia: a systematic review. *Ann Intern Med.* 2018;168(1):30–38. doi:10.7326/M17-1528
61. Halloway S, Wilbur J, Schoeny ME, Arfanakis K. Effects of endurance-focused physical activity interventions on brain health: a systematic review. *Biol Res Nurs.* 2017;19(1):53–64. doi:10.1177/1099800416660758