DigitCult | Scientific Journal on Digital Cultures

Eyewear Equipped with a Triaxial Accelerometer Detects Age-Related Changes in Ambulatory Activity

Shigeyuki Ikeda
Department of Ubiquitous Sensing
Institute of Development, Aging and Cancer
Tohoku University

Susumu Ichinohe
JINS MEME Div. JINS Inc.

Ryuta Kawashima
Department of Ubiquitous Sensing
Department of Functional Brain Imaging
Department of Functional Brain Imaging
Institute of Development, Aging and Cancer
Tohoku University

Abstract

Aging is known as a risk factor for gait disorders, which lead to reduced quality of life. Gait disorders can potentially be a sign of a preclinical phase of neurological diseases. Therefore, routine monitoring of changes in ambulatory activity with age can lead to early detection of such disorders. JINS MEME is eyewear equipped with a triaxial accelerometer (mediolateral, anteroposterior, and vertical) and capable of measuring acceleration signals during gait. To validate effectiveness of JINS MEME in routinely monitoring age-related changes in ambulatory activity, the present study tested three hypotheses: (1) the frequency of mediolateral body sway during gait increases with age, (2) the variability of gait speed (anteroposterior) increases with age, and (3) the frequency of vertical body sway during gait increases with age. The present study included 118 subjects aged 25–69 years. The acceleration signals were measured by JINS MEME while each subject walked down a barrier-free 20-meter-long level corridor at a natural pace. Triaxial variances known for reflecting gait stability, were calculated from the acceleration signals during gait. An association between each of the triaxial variances and age was assessed by multiple linear robust regression analysis including sex as a nuisance covariate. We found significant positive correlations between the anteroposterior variance and age and between the vertical variance and age. The results supported our second and third hypotheses and raised an intriguing possibility that the triaxial accelerometer of JINS MEME is capable of detecting age-related changes in ambulatory activity.

Published 29 November 2017

Correspondence should be addressed to Shigeyuki Ikeda, Department of Ubiquitous Sensing, Institute of Development, Aging and Cancer, Tohoku University, 2 Chome-1-1 Katahira, Aoba Ward, Sendai, Miyagi Prefecture 980-8577, Japan. Email: shigeyuki.ikeda.e2@tohoku.ac.jp

DigitCult, Scientific Journal on Digital Cultures is an academic journal of international scope, peer-reviewed and open access, aiming to value international research and to present current debate on digital culture, technological innovation and social change. ISSN: 2531-5994. URL: http://www.digitcult.it

Introduction

Falls in the elderly tend to occur when walking (Cali and Kiel 1995; Norton et al. 1997), and human gait has been known to undergo age-related changes. For example, gait speed was reportedly reduced with advancing age (Oberg, Karsznia, and Oberg 1993; Bohannon 1997; Callisaya et al. 2008; Callisaya et al. 2010; Park et al. 2016), and it has been shown that the elderly exhibit changes in walking stability, i.e., a more conservative gait pattern (Menz et al. 2003). Besides age, cognitive ability has been known to correlate with measures of physical ability. For example, elderly individuals with reduced handgrip strength exhibited a significant decline in cognitive function (Alfaro-Acha et al. 2006); cognitive declines were associated with weaknesses in walking at a normal pace (Tabbarah, Crimmins, and Seeman 2002); reduction of gait speed correlated with cognitive declines (Marquis et al. 2002; Alfaro-Acha et al. 2007; Inzitari et al. 2008; Soumare et al. 2009; Atkinson et al. 2010); and the elderly with shorter step lengths were shown to have a higher risk of cognitive decline (Taniguchi et al. 2012). As suggested by these findings, gait is linked to aging and cognitive decline. In theory, routine monitoring of a person’s ambulatory activity may contribute in detecting a preclinical phase of neurological diseases.

To achieve routine monitoring of ambulatory activity, it is desirable to use a wearable device which is capable of single-handedly recording ambulatory activity. To our knowledge, most previous studies focusing on ambulatory activity used systems or devices dedicated for recording ambulatory activity (e.g., sensors attached to the body and treadmill). In some cases, professional staff were employed to assess a subjects’ gait performance. The present study used JINS MEME to record ambulatory activity. This is eyewear equipped with a triaxial accelerometer, and recording data does not require an expert (Ishimaru et al. 2014; Kanoh et al. 2015). JINS MEME promises to monitor ambulatory activity without interrupting daily life.

The elderly are known to undergo age-related physiological changes, e.g., decline in limb strength. Therefore, gait stability must decline with age. Measuring acceleration during gait was an effective evaluation of gait stability (Senden et al. 2012; Nakano et al. 2013). A triaxial accelerometer previously revealed significant differences in acceleration signals between young and old subjects (Menz et al. 2003). The triaxial accelerometer in JINS MEME is therefore expected to detect age-related changes in gait stability. To assess the changes in gait stability, the present study used variability of signals recorded by the accelerometer, which reflects gait stability (Menz, Lord, and Fitzpatrick 2003; Senden et al. 2012; Nakano et al. 2013). The main objective of the present study is to validate effectiveness of JINS MEME in monitoring age-related changes in ambulatory activity. To this end, the present study tested the following hypotheses:

- If the frequency of mediolateral body sway during gait increases because of a decline in gait stability with age, then variability of mediolateral acceleration signals during gait should increase with age.

- If the stability of gait speed (anteroposterior) decreases because of a decline in gait stability with age, then variability of anteroposterior acceleration signals during gait should increase with age.

- If the frequency of vertical body sway during gait increases because of a decline in gait stability with age, then variability of vertical acceleration signals during gait should increase with age.

To test our hypotheses, triaxial acceleration signals were measured using JINS MEME while subjects walked along a 20-meter-long straight corridor. Triaxial variances were calculated from the measured acceleration signals. We subsequently applied multiple linear robust regression analysis to the variance data to analyze our data.

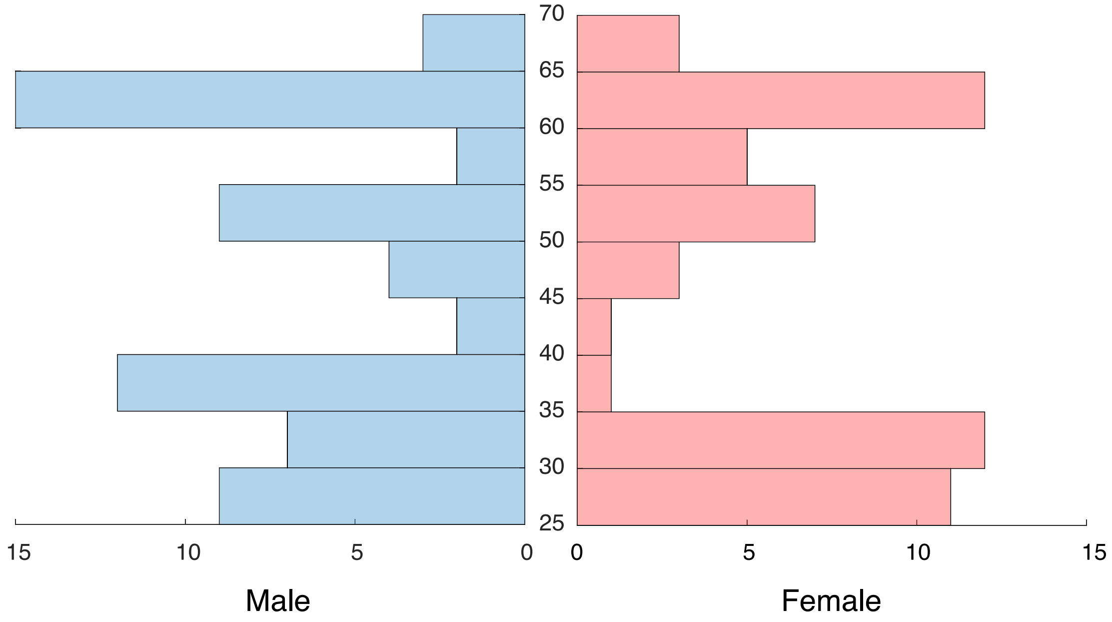

Figure 1. Age and sex distribution of study subjects. The y-axis represents age-groups and the x-axis represents the number of subjects within each age-group.

Materials and Methods

Subjects

The study included 118 healthy Japanese subjects (63 males and 55 females; age 25–69 years; 45.5 ± 14.0 years, mean ± SD). The subjects had normal or corrected-to-normal vision and could walk unassisted. Number of subjects for each half decade of age and sex is shown in Figure 1.

JINS MEME Measurement

To record ambulatory activity, we used JINS MEME (Ishimaru et al. 2014; Kanoh et al. 2015), which is equipped with a triaxial accelerometer (x: mediolateral direction; y: anteroposterior direction; z: vertical direction; Figure 2). Signals from the accelerometer were converted from analog to digital data (resolution, 16 bits; sampling rate, 100 Hz) by the A/D converter in JINS MEME. The digital data was transmitted to a PC by Bluetooth LE. To receive the digital data on PC, we used "Designated viewer", which is a software designed for receiving digital data from JINS MEME and runs on the used operating system Microsoft Windows 8.1 (64bit). Electrical power was provided to JINS MEME by a built-in rechargeable lithium-ion battery (continuous use: up to 16 hours). The weight of JINS MEME was approximately 36 g.

Experimental Conditions

Each subject wearing JINS MEME performed an experimental session, which comprised two rest blocks and two blocks of gait (Figure 3). In the first rest block, the subjects were instructed to remain standing for five seconds; in the first block of gait, the subjects were instructed to walk down a barrier-free 20-meter-long level corridor at a natural pace (Figure 4); in the second rest block the subjects were instructed to turn around after remaining standing for first five seconds, and to remain standing for another five seconds; in the second block of gait the subjects were instructed to walk back down the corridor to the original start at a natural pace.

 DOI:10.4399/97888255088951

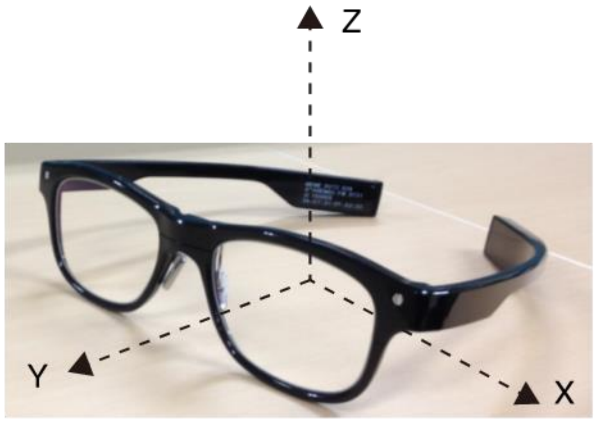

Figure 2. JINS MEME with a triaxial accelerometer (x: mediolateral, y: anteroposterior, z: vertical). We used a version of JINS MEME, which is designed specifically for academic research purposes (for details, https://jins-meme.com/en/academic/).

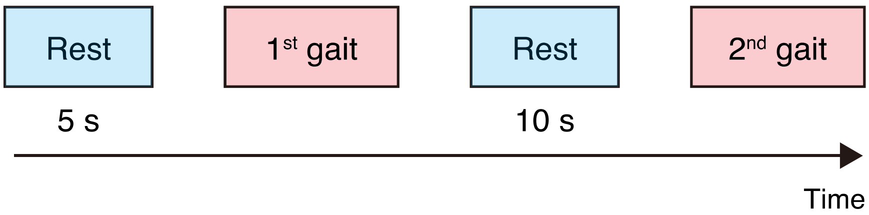

Figure 3. Experimental procedure of a session.

Figure 4. Experimental environment. (A) Gait condition. (B) Barrier-free 20-meter level corridor used in the experiment. (C) Floor on which loose carpet tiles were spread.

Data Analysis

Data analysis in the present study was accomplished with Matlab (Version 9.0.1, Mathworks Inc., Natick, MA, USA). Data analysis consisted of summarization of the acceleration signals and a subsequent regression analysis to test our hypotheses. The procedure of the summarization of the acceleration signals was as follows: first, triaxial acceleration signals during each block of gait were extracted; second, eighth order polynomial detrending was applied to the extracted signals to remove low-frequency drifts; third, variances were calculated from the detrended signals to estimate fluctuation of acceleration signals of each axis during gait; fourth, the variances were averaged across the two blocks of gait separately for the triaxial acceleration signals; lastly, the averaged variances for each axis were z-normalized across the subjects. In a regression analysis, an association between the normalized variances for each axis and the age of the subjects was assessed using robust linear regression including sex as a nuisance covariate (i.e., Variance ~ 1 + Age + Sex). Age was treated as a continuous variable. Robustness of the regression was approached by bisquare weighting. We performed t-tests and calculated the corresponding p-values of regression coefficients between the variances and age, and then investigated whether the coefficients were statistically significant (two-tailed t-test, $p < 0.05$).

Results

To investigate associations between each of the triaxial variances and age of the subjects, we performed robust linear regression analysis. We then investigated whether the regression coefficient of each axis with age was statistically significant. As shown in Figure 5, we confirmed that age was not correlated with the variances recorded on the x-axis (*Coef.* = 5.5×10^{-3}, t_{115} = 0.85, p = 0.397). On the other hand, age significantly positively correlated with the variances recorded on the y and z axes (y: *Coef.* = 0.017, t_{115} = 3.5, $p = 6.7 \times 10^{-4}$; z: *Coef.* = 0.014, t_{115} = 2.8, $p = 5.3 \times 10^{-3}$). The obtained results supported the second and third of our hypotheses.

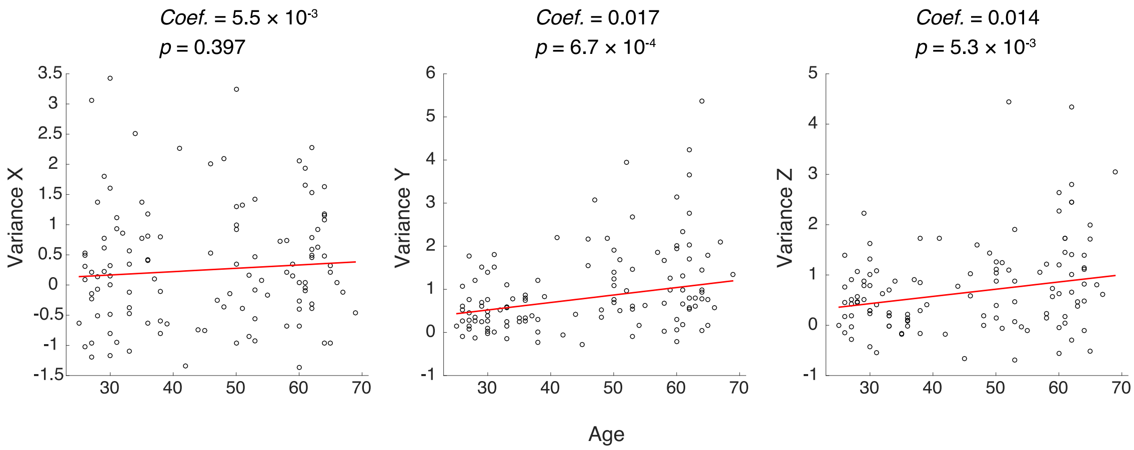

Figure 5. Associations between each of the triaxial variances (x: mediolateral, y: anteroposterior, z: vertical) and age. Each scatter plot shows the relationship between the variances calculated from the acceleration signals during gait and age of the subjects. "Coef." represents the regression coefficient between the variances and age. The nuisance covariates (i.e., sex and an intercept) were regressed out from the variances. Each red line shows variances estimated from age.

Discussion

To validate the effectiveness of JINS MEME in monitoring age-related changes in ambulatory activity, we tested three hypotheses. Our findings show that:

- The variances of the x-axis (mediolateral) acceleration signals did not significantly correlate with age.

- The variances of the y-axis (anteroposterior) acceleration signals significantly positively correlated with age.

- The variances of the z-axis (vertical) acceleration signals significantly positively correlated with age.

The findings supported the second and third of our hypotheses but not the first hypothesis. The present study suggests that JINS MEME is effective in routinely monitoring age-related changes in ambulatory activity.

For the x-axis (mediolateral), JINS MEME could not reveal a significant correlation between the variances and age. A possible explanation is that the mediolateral variances reflected individual differences rather than age-related frequency of body sway. Previous studies confirmed an effect of age on mediolateral accelerations, i.e., the elderly exhibited larger root mean square (RMS) values of mediolateral acceleration signals during gait than the young (Menz et al. 2003; Mazzà et al. 2008). The inconsistency may lie in differences in age-groups of elderly subjects. In contrast to our study population, the previous studies focused on subjects older than 70 years.

For the y-axis (anteroposterior), JINS MEME showed a significant positive correlation between the variances and age. The obtained results supported our second hypothesis that the stability of gait speed decreases because of a decline in gait stability with age. Inconsistent with our results, previous studies observed no significant differences between the young and elderly in RMS values of anteroposterior acceleration signals during gait (Menz et al. 2003; Mazzà et al. 2008). Reportedly, ethnic differences in gait speed exist, e.g., Japanese elderly exhibit faster gait speed than elderly Caucasians (Aoyagi et al. 2001) and non-Asian elderly people in general (Ando et al. 2015). Our facts suggest that changes in ambulatory activity with age of Japanese individuals show a pattern different from that of populations in the previous studies. Thus, ethnical differences may cause the inconsistency between our results and the previous results.

For the z-axis (vertical), JINS MEME showed a significant positive correlation between the variances and age. The obtained results supported our third hypothesis that the frequency of vertical body sway during gait increases because of a decline in gait stability with age. Conversely, previous studies showed that the elderly exhibited significantly smaller RMS values of vertical accelerations during gait than the young (Menz et al. 2003; Mazzà et al. 2008). The elderly have generally been known to exhibit a more conservative gait pattern, which leads to a reduction in magnitude of accelerations. This may reflect a compensatory strategy to maintain balance under declining physiological functions, e.g., lower limb strength (Menz et al. 2003). Further research is needed to reveal an association between variability of vertical accelerations during gait and aging.

Although the present study suggests the effectiveness of JINS MEME in routinely monitoring ambulatory activity, it has four important limitations:

- As shown in Figure 1, the sample size of our populations was relatively small in the range from 40–45 and 65–70 years; in addition, it was uneven at each gender (particularly in 35–40 years). A larger and gender-balanced sample ought to provide more precise data on ambulatory activity changes with age.

- It is unclear exactly whether our findings reflect age-related changes in gait because the cross-sectional design was employed in the present study.

- Flooring may affect gait. The present study used a corridor on which loose carpet tiles were spread. Additional research is needed to investigate effects of different flooring on acceleration signals from JINS MEME.

- Shoes and clothing worn by the subjects were not uniform across the study subjects. As materials of soles and stretch of clothes may affect ambulatory activity, such effects should be considered in future research.

Acknowledgements

We thank K. Inoue, M. Kimura, H. Watanabe, and Y. Uema who belong to JINS Inc. for supporting the present study. We also thank the participants of the present study.

References

Alfaro-Acha, Ana, S Al Snih, Mukaila A Raji, Yong-fang F Kuo, Kyriakos S Markides, Kenneth J Ottenbacher, Soham Al Snih, et al. 2006. "Handgrip Strength and Cognitive Decline in Older Mexican Americans." *J Gerontol A Biol Sci Med Sci* 61 (8): 859–65. doi:61/8/859 [pii].

Alfaro-Acha, Ana, Soham Al Snih, Mukaila A. Raji, Kyriakos S. Markides, Kenneth J. Ottenbacher, and Soham Al. 2007. "Does 8-Foot Walk Time Predict Cognitive Decline in Older Mexicans Americans?" *Journal of the American Geriatrics Society* 55 (2): 245–51. doi:10.1111/j.1532-5415.2007.01039.x.

Ando, Masataka, Naoto Kamide, M A, N K, Masataka Ando, and Naoto Kamide. 2015. "Japanese Elderly Persons Walk Faster than Non-Asian Elderly Persons: A Meta-Regression Analysis." *Journal of Physical Therapy Science* 27 (11): 3481–85. doi:10.1589/jpts.27.3481.

Aoyagi, Kiyoshi, Philip D Ross, Michael C Nevitt, James W Davis, Richard D Wasnich, Takuo Hayashi, and Tai-ichiro Takemoto. 2001. "Comparison of Performance-Based Measures among Native Japanese, Japanese-Americans in Hawaii and Caucasian Women in the United States, Ages 65 Years and over: A Cross-Sectional Study." *BMC Geriatrics* 1: 3. doi:10.1186/1471-2318-1-1.

Atkinson, Hal H, Stephen R Rapp, Jeff D Williamson, James Lovato, John R Absher, Margery Gass, Victor W Henderson, et al. 2010. "The Relationship between Cognitive Function and Physical Performance in Older Women: Results from the Women's Health Initiative Memory Study." *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 65 (3): 300–306. doi:10.1093/gerona/glp149.

Bohannon, Richard W. 1997. "Comfortable and Maximum Walking Speed of Adults Aged 20-79 Years: Reference Values and Determinants." *Age and Ageing* 26 (1): 15–19. doi:10.1093/ageing/26.1.15.

Cali, C M, and D P Kiel. 1995. "An Epidemiologic Study of Fall-Related Fractures Among Institutionalized Older People." *Journal of the American Geriatrics Society* 43 (12): 1336–40. doi:10.1111/j.1532-5415.1995.tb06610.x.

Callisaya, Michele L., Leigh Blizzard, Michael D. Schmidt, Jennifer L. McGinley, and Velandai K. Srikanth. 2008. "Sex Modifies the Relationship Between Age and Gait: A Population-Based Study of Older Adults." *Journal of Gerontology* 63A (2): 165–70. doi:10.1016/j.aqpro.2013.07.003.

———. 2010. "Ageing and Gait Variability-a Population-Based Study of Older People." *Age and Ageing* 39 (2): 191–97. doi:10.1093/ageing/afp250.

Inzitari, Marco, Anne B. Newman, Kristine Yaffe, Robert Boudreau, Nathalie De Rekeneire, Ronald Shorr, Tamara B. Harris, and Caterina Rosano. 2008. "Gait Speed Predicts Decline in Attention and Psychomotor Speed in Older Adults: The Health Aging and Body Composition Study." *Neuroepidemiology* 29 (3–4): 156–62. doi:10.1159/000111577.

Ishimaru, Shoya, Yuji Uema, Kai Kunze, Koichi Kise, Katsuma Tanaka, and Masahiko Inami. 2014. "Smarter Eyewear: Using Commercial EOG Glasses for Activity Recognition." In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*, 239–42. doi:10.1145/2638728.2638795.

Kanoh, S., S. Ichi-Nohe, S. Shioya, K. Inoue, and R. Kawashima. 2015. "Development of an Eyewear to Measure Eye and Body Movements." *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS* 2015–Novem: 2267–70. doi:10.1109/EMBC.2015.7318844.

Marquis, S, M Milar Moore, D B Howieson, G Sexton, H Payami, J A Kaye, and R Camicioli. 2002. “Independent Predictors of Cognitive Decline in Healthy Elderly Persons.” *Archives of Neurology* 59 (4): 601–6. http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L34289964%5Cnhttp://sfx.library.uu.nl/utrecht?sid=EMBASE&issn=00039942&id=doi:&atitle=Independent+predictors+of+cognitive+decline+in+healthy+elderly+persons&stitle=Arch.+Neurol.&titl.

Mazzà, Claudia, Marco Iosa, Fabrizio Pecoraro, Aurelio Cappozzo, P. Picerno, F. Masala, and Aurelio Cappozzo. 2008. “Control of the Upper Body Accelerations in Young and Elderly Women during Level Walking.” *Journal of NeuroEngineering and Rehabilitation* 5 (30): 1–10. doi:10.1186/1743-0003-5-30.

Menz, Hylton B., Stephen R. Lord, and Richard C. Fitzpatrick. 2003. “Acceleration Patterns of the Head and Pelvis When Walking on Level and Irregular Surfaces.” *Gait and Posture* 18 (1): 35–46. doi:10.1016/S0966-6362(02)00159-5.

Menz, Hylton B, Stephen R Lord, Richard C Fitzpatrick, and High Street. 2003. “Age-Related Differences in Walking Stability.” *Age and Ageing* 32 (2): 137–42. doi:10.1093/ageing/32.2.137.

Nakano, Hideki, Makoto Nozaki, Kozo Ueta, Michihiro Osumi, Seigou Kawami, and Shu Morioka. 2013. “Effect of a Plantar Perceptual Learning Task on Walking Stability in the Elderly: A Randomized Controlled Trial.” *Clinical Rehabilitation* 27 (7): 608–15. doi:10.1177/0269215512471062.

Norton, Robyn, A John Campbell, Trevor Lee-Joe, E Robinson, and M Butler. 1997. “Circumstances of Falls Resulting in Hip Fractures among Older People.” *Journal of the American Geriatrics Society* 45 (9): 1108–12. doi:10.1111/j.1532-5415.1997.tb05975.x.

Oberg, Tommy, Alek Karsznia, and Kurt Oberg. 1993. “Basic Gait Parameters: Reference Data for Normal Subjects, 10-79 Years of Age.” *Journal of Rehabilitation Research and Development* 30 (2): 210–23. doi:10.1080/19397030902947041.

Park, Jeong-Ho, Martina Mancini, Patricia Carlson-Kuhta, John G. Nutt, and Fay B. Horak. 2016. “Quantifying Effects of Age on Balance and Gait with Inertial Sensors in Community-Dwelling Healthy Adults.” *Experimental Gerontology* 85. Elsevier B.V.: 48–58. doi:10.1016/j.exger.2016.09.018.

Senden, R., H. H.C.M. Savelberg, B. Grimm, I. C. Heyligers, and K. Meijer. 2012. “Accelerometry-Based Gait Analysis, an Additional Objective Approach to Screen Subjects at Risk for Falling.” *Gait and Posture* 36 (2). Elsevier B.V.: 296–300. doi:10.1016/j.gaitpost.2012.03.015.

Soumare, A, Béatrice Tavernier, A Alperovitch, Christophe Tzourio, Alexis Elbaz, Aïcha Soumaré, Béatrice Tavernier, Annick Alpérovitch, Christophe Tzourio, and Alexis Elbaz. 2009. “A Cross-Sectional and Longitudinal Study of the Relationship between Walking Speed and Cognitive Function in Community-Dwelling Elderly People.” *J Gerontol A Biol Sci Med Sci* 64 (10): 1058–65. doi:10.1093/gerona/glp077.

Tabbarah, Melissa, Eileen M. Crimmins, and Teresa E. Seeman. 2002. “The Relationship Between Cognitive and Physical Performance: MacArthur Studies of Successful Aging.” *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 57 (4): M228–35. doi:10.1093/gerona/57.4.M228.

Taniguchi, Yu, Hiroto Yoshida, Yoshinori Fujiwara, Yutaka Motohashi, and Shoji Shinkai. 2012. “A Prospective Study of Gait Performance and Subsequent Cognitive Decline in a General Population of Older Japanese.” *Journals of Gerontology - Series A Biological Sciences and Medical Sciences* 67 A (7): 796–803. doi:10.1093/gerona/glr243.