Acceleration-based gait analysis: accelerating mobility assessment in older adults

Editorial

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Mobility is defined as the ability to move one's own body through space, and includes activities such as walking, standing up, turning over in bed and climbing stairs. Walking is viewed as a fundamental mobility task for human life, as it is a key component of both basic and instrumental activities of daily living. It is a complex neuromotor activity, influenced by the status of cardiovascular, neurologic, musculoskeletal, and cognitive systems. Rich empirical evidence shows that objective measurement of walking speed and characteristics of the stepping pattern (cadence, step length and width, variability) are powerful predictors of future health and mortality in older adults [1,2].

Given the usefulness of walking speed and other simple metrics of the stepping pattern, why investigate other measures of walking ability? First, many older adults do walk at a near normal or normal speed, yet there is evidence that the underlying control of gait changes even in healthy aging [3,4]. Second, there is significant research interest in gait control in patient groups with neurologic conditions such as Parkinson's disease (PD) and stroke which are more prevalent with aging. Individuals in the earlier stages of PD or on anti-Parkinson medications, and individuals post stroke may exhibit walking speeds and stepping characteristics similar to those of healthy peers [5,6]. Thus, while important indicators of overall function, simple gait metrics do have limitations in their ability to discriminate between age- and disease related gait dysfunction. These limitations may be explained by the fact that speed and stepping characteristics are outcome variables. For example, the measures of step time and step length tell us the time and distance from one heel strike event to the next heel strike, but they do not provide information about the quality of body motion during that time. Some older adults may walk slower with "good" motor control or control similar to young adults; and some, with or without the presence of diagnosed disease, may walk at normal speeds with altered control.

Thus, there is need for process measures that will directly assess quality of movement control during walking, and indicate differences and changes in control not detected by simple gait metrics. One such process measure is the direct measurement of body accelerations during walking. The method of using accelerometers to directly measure body accelerations is known as acceleration-based gait analysis (AGA), and it has garnered increasing interest from gait researchers in the past decade. In the following paragraphs, we will briefly relate why acceleration of the body during walking is an important movement characteristic, highlight the research findings about one particular acceleration measure - walking smoothness, and suggest future research directions.

Acceleration is the rate of change of velocity with time. While the term is often used to mean a state of increasing speed, any change in the velocity results in acceleration: increasing speed, decreasing speed, or changing direction. During routine walking, the body's center of mass changes velocity in all three directions of motion (anteroposterior, mediolateral, and

vertical) resulting in distinct acceleration profiles that are regular and repeatable from step to step. When an accelerometer is secured to the lower trunk, the recorded accelerations serve as a proxy for accelerations of the body's center of mass and are hence indicative of global body control during walking. Any change in velocity of the center of mass occurring during a very short period of time results in a large acceleration; consequently, the lower trunk acceleration signal amplifies, or is sensitive to, even small, subtle changes in the control of the center of mass. During walking, lower extremity muscle activations accelerate and decelerate the body's center of mass. Abnormalities in the timing and magnitude of muscle activations and force generation can cause aberrant accelerations/decelerations of the center of mass which in turn will be reflected in abnormal lower trunk acceleration profiles. Abnormal lower extremity muscle activations are evident even in active, healthy older adults walking at normal speeds [7]; thus, abnormal lower trunk acceleration profiles are expected, and can reflect early, subclinical changes in global gait control in older adults.

Not only is acceleration a sensitive measure, it is a measure relatively easy to collect. Direct recording of 3D accelerations of the body during walking is typically achieved using a single triaxial accelerometer. Accelerometers are now small, low cost and wireless, enabling testing in real world environments, minimal set-up time, and the ability to walk naturally without hindrance.

While the information from the acceleration signal can be potentially useful, how is meaningful information from the acceleration profile quantified? How are acceleration profiles compared across time (pre- and post-intervention) or between individuals or groups? For better or for worse, the answer is there are many different ways of processing and analyzing the acceleration signal. As the interest in AGA increases, the number of ways researchers find to extract information and analyze the signal increases. Consequently, there are many acceleration measures used for gait analysis with a relatively small body of research investigating each measure. The processing required for many acceleration measures is complex, often necessitating a bioengineer or expert in signal processing be a key member of a clinical gait research team. As description of all current measures is beyond the scope of this article, we refer the readers to a thorough review by Kavanagh & Menz, 2008 [8]. As an example of the usefulness of acceleration data we will summarize the findings for one measure, gait smoothness.

As clinicians, we might describe smooth walking as easy, rhythmical, regular, or not awkward or jerky. The smoothness measure captures this movement quality by quantifying deviations in both acceleration magnitude and timing from an ideally symmetrical acceleration pattern; smoothness values are determined per stride then averaged across strides for each direction of motion; higher values indicate greater smoothness of walking [9]. Healthy older

adults have reduced smoothness compared to young adults even though both groups walked at similar preferred speeds [10,11]. Persons in the early stages of PD had reduced walking smoothness compared to healthy older adults even after accounting for differences in walking speed [5]. Several studies have shown that older adult fallers have reduced smoothness in comparison to non-fallers [12], and a recent prospective study found that smoothness predicted the incidence of falls in older adults independent of physical function [13]. We found that greater walking smoothness was associated with better self-reported physical function independent of gait speed in a sample of community dwelling older adults [14]. Together, these data indicate that smoothness is able to detect motor control abnormalities when speed and other simple metrics do not, and it represents aspects of the motor control of walking important for physical function not represented by gait speed alone. One limitation of the smoothness measure is that it does not indicate the specific problems or impairments causing a reduction in the global motor control of walking.

While gait smoothness and other acceleration measures appear to offer a window into the underlying control of gait, there are several methodological concerns common among measures using acceleration signals. Unfortunately, there is not a standard approach to dealing with these concerns among gait researchers which makes comparing and summarizing the findings across studies difficult. In particular, there are a number of different ways to pre-process gait acceleration signals in order to remove excessive noise or to account for the accelerometer tilt [15]. Needless to say, one can obtain different results depending on pre-processing steps, even when using a same dataset. The question about extracting traditional gait parameters such as stride intervals from acceleration signals is still open as well. We urge gait researchers using acceleration measures to be transparent and detailed in reporting all pre-processing steps in their methodology to allow for replication, and so that direct comparisons between methodologies can be investigated.

We offer several suggestions for advancing AGA research. First, researchers need to compare and contrast the most commonly used acceleration measures to determine if the measures are redundant or complimentary. Second, standardization of signal pre-processing and the procedure for the derivation of each measure is needed to ultimately develop normative ranges for acceleration measures. Third, the vast majority of studies using AGA have been cross-sectional, observational studies designed to examine group differences in the measure (e.g. young vs. older adult, healthy older adult vs. PD). Longitudinal studies are needed to determine if acceleration measures can detect changes in mobility over time in older adults, changes in disease progression, or if changes in the measures are predictive of the development of disease (e.g. PD). Fourth, to our knowledge, no gait rehabilitation or exercise intervention study has used an acceleration measure as a primary outcome variable. We anticipate that considering acceleration measures such as walking smoothness in addition to

gait speed and other simple metrics will provide a holistic gait analysis that assesses both functional performance and the level of motor control. Interventions improving different traditional gait and acceleration measures may ultimately have a greater impact on improving or maintaining function and preventing disability in older adults.

In summary, acceleration measures are often used to quantify movement quality and have demonstrated the ability to detect differences in movement control during walking when speed and simple gait metrics do not. The evidence from the foundational work in AGA to date suggests that it may play an important role in detecting early change in mobility in older adults, subtle alternations in preclinical phases of disease, and in determining the effectiveness of an intervention to improve or maintain walking ability in older adults.

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References

1. Brach JS, Studenski SA, Perera S, VanSwearingen JM, Newman AB. Gait variability and the risk of incident mobility disability in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci.* 62(9), 983-988 (2007).

2. Studenski S, Perera S, Patel K, et al. Gait speed and survival in older adults. *Jama.* 305(1), 50-58 (2011).

3. Van Emmerik RE, McDermott WJ, Haddad JM, Van Wegen EE. Age-related changes in upper body adaptation to walking speed in human locomotion. *Gait Posture.* 22(3), 233-239 (2005).

4. Winter DA, Patla AE, Frank JS, Walt SE. Biomechanical walking pattern changes in the fit and healthy elderly. *Phys Ther.* 70(6), 340-347 (1990).

5. Lowry KA, Smiley-Oyen AL, Carrel AJ, Kerr JP. Walking stability using harmonic ratios in Parkinson's disease. *Mov Disord.* 24(2), 261-267 (2009).

6. Van Emmerik RE, Wagenaar RC, Winogrodzka A, Wolters EC. Identification of axial rigidity during locomotion in Parkinson disease. *Arch Phys Med Rehabil.* 80(2), 186-191 (1999).

7. Schmitz A, Silder A, Heiderscheit B, Mahoney J, Thelen DG. Differences in lower-extremity muscular activation during walking between healthy older and young adults. *J Electromyogr Kinesiol.* 19(6), 1085-1091 (2009).

8. Kavanagh JJ, Menz HB. Accelerometry: a technique for quantifying movement patterns during walking. *Gait Posture.* 28(1), 1-15 (2008).

9. Bellanca JL, Lowry KA, Vanswearingen JM, Brach JS, Redfern MS. Harmonic ratios: a quantification of step to step symmetry. *J Biomech.* 46(4), 828-831 (2013).

10. Brach JS, McGurl D, Wert D, et al. Validation of a measure of smoothness of walking. *J Gerontol A Biol Sci Med Sci.* 66(1), 136-141 (2011).

11. Lowry KA, Lokenvitz N, Smiley-Oyen AL. Age- and speed-related differences in harmonic ratios during walking. *Gait Posture.* 35(2), 272-276 (2012).

12. Menz HB, Lord SR, Fitzpatrick RC. Acceleration patterns of the head and pelvis when walking are associated with risk of falling in community-dwelling older people. *J Gerontol A Biol Sci Med Sci.* 58(5), M446-452 (2003).

13. Doi T, Hirata S, Ono R, Tsutsumimoto K, Misu S, Ando H. The harmonic ratio of trunk acceleration predicts falling among older people: results of a 1-year prospective study. *J Neuroeng Rehabil.* 10, 7 (2013).

14. Lowry KA, Vanswearingen JM, Perera S, Studenski SA, Brach JS. Walking Smoothness Is Associated With Self-Reported Function After Accounting for Gait Speed. *J Gerontol A Biol Sci Med Sci.* (2013).

15. Sejdic E, Lowry K, Roche J, Redfern M, Brach J. A Comprehensive Assessment of Gait Accelerometry Signals in Time, Frequency and Time-Frequency Domains. *IEEE Trans Neural Syst Rehabil Eng.* (2013).