



Original Article

The validity of an accelerometer-based method for estimating fluidity in the sit-to-walk task in a community setting

TOMOYUKI ASAKURA, PhD^{1*}, YOSHIYUKI MIYAZAWA, MSc²⁾, SHIGERU USUDA, PhD¹⁾

¹⁾ Gunma University Graduate School of Health Sciences: 3-39-22 Showa, Maebashi, Gunma 371-8514, Japan

²⁾ Geriatrics Research Institute and Hospital, Japan

Abstract. [Purpose] Fluidity in the sit-to-walk task has been quantitatively measured with three-dimensional motion analysis system. The purpose of this study was to determine the validity of an accelerometer-based method for estimating fluidity in community-dwelling elderly individuals. [Subjects and Methods] Seventeen community-dwelling elderly females performed a sit-to-walk task. The motion was recorded by an accelerometer, a three-dimensional motion analysis system and a foot pressure sensor simultaneously. The timings of events determined from the acceleration waveform were compared to the timings determined from the three-dimensional motion analysis data (task onset, maximum trunk inclination) or foot pressure sensor data (first heel strike). Regression analysis was used to estimate the fluidity index from the duration between events. [Results] The characteristics of the acceleration waveform were similar to those previously reported in younger adults. Comparisons of event timings from accelerometer and motion analysis system data indicated no systematic bias. Regression analysis showed that the duration from maximum trunk inclination to the first heel strike was the best predictor of fluidity index. [Conclusion] An accelerometer-based method using the duration between characteristic events may be used to precisely and conveniently assess fluidity in a sit-to-walk task in a community setting.

Key words: Accelerometer, Sit-to-walk task, Fluidity

(This article was submitted Sep. 12, 2016, and was accepted Oct. 17, 2016)

INTRODUCTION

Accelerometers are increasingly being used for motion analysis or measuring physical activity because of their availability and portability^{1–11)}. An accelerometer is incorporated into most smartphones. Therefore, studies based on smartphone use also have increased^{12–15)}. As a motion analysis tool, accelerometers have been used for gait and the sit-to-stand movement^{5–11)}. In these reports, the validity or usability has been approved by comparison to three-dimensional analysis systems or force plates, which are the gold standard. These reports have shown that it is possible to use accelerometers for objective assessment.

We have studied the sit-to-walk (STW) task using a three-dimensional analysis system^{16, 17)}. STW is a transitional activity that includes standing from a chair and gait initiation^{18–20)}. In healthy persons, gait is initiated before the completion of standing up. Malouin and Dion termed this ability or strategy ‘fluidity’ or the ‘fluid strategy’^{21, 22)}. They showed that the fluidity of post-stroke persons was lower than that of healthy persons²¹⁾. Differences in the strategy between young and elderly persons have also been identified using ground reaction forces and motion speed²³⁾. Fluidity can be assessed using the fluidity index (FI), which is calculated from the momentum of the body center of gravity, quantified using a three-dimensional analysis system^{21, 22)}. Another assessment tool, the fluidity scale, has also been established²¹⁾. In this scale, fluidity is assessed on four-point graded ordinal scale by macroscopy. These assessment tools have merit and defects. For FI, the assessment is

*Corresponding author. Tomoyuki Asakura (E-mail: asakuri@gunma-u.ac.jp)

©2017 The Society of Physical Therapy Science. Published by IPEC Inc.

This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License <<http://creativecommons.org/licenses/by-nc-nd/4.0/>>.

Table 1. Previous medical history and long term care need (support) level of subjects

Diseases	Number
Cerebral infarction	2
Parkinson's disease	1
Fracture of lower limbs or pelvis	2
Spine disease	3
Osteoarthritis of lower limbs	2
None	7
Long-term care need (support) level	
Support need level 1	2
Support need level 2	3
Long-term care need level 1	2
None	10

Support need level 1, 2: persons requiring daily support as they are at risk of being in need of long-term care. Long-term care need level 1: a condition assumed to require care in daily activities due to physical or mental problems. In care-need certification reference time, persons in support need level 1 need something supports for 25–32 minutes per a day. Persons in support need level 2 need supports for 32–50 minutes per a day. Persons in Long-term care need level 1 need care for 32–50 minutes per a day.

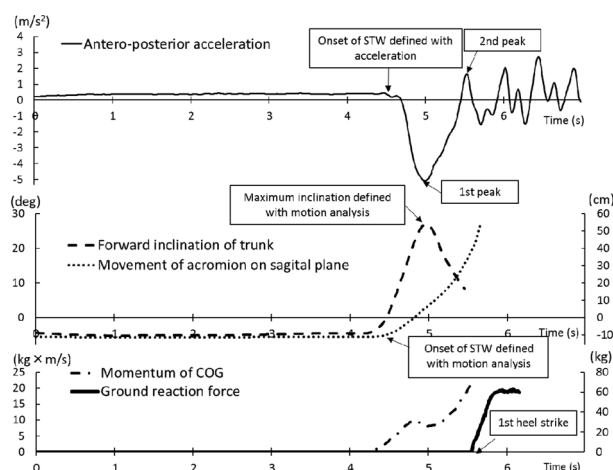


Fig. 1. A typical acceleration waveform and definitions of events from acceleration and reference data

In acceleration, a negative change indicates anterior trunk inclination or backward acceleration. A positive change indicates posterior trunk inclination or forward acceleration. When the trunk inclines, the accelerometer detects gravitational acceleration.

STW: sit-to-walk task; COG: center of gravity

objective and precise but the measurement setting is limited to the laboratory. On the other hand, the fluidity scale doesn't require special equipment but it's difficult to quantify small changes. We have suggested using an accelerometer to resolve these problems and have reported the validity of this approach²⁴). However, validity was evaluated only in healthy young adults. It is thought that fluidity will be lower in elderly persons or persons with disability than in healthy young adults, and the characteristics of the accelerometer waveform may be different from that in healthy adults.

The purpose of this study was to quantify the validity of an accelerometer-based method for estimating fluidity in community-dwelling elderly individuals.

SUBJECTS AND METHODS

Seventeen subjects (mean \pm standard deviation, age: 76.1 ± 7.6 years, height: 151.5 ± 5.4 cm, weight: 47.6 ± 5.6 kg, all female) attending a day care facility established together with a training gym for the elderly participated in this study. Some subjects had a notable medical history and certification of long-term care insurance. However, all subjects could walk more than 20 m without using a cane and could stand up without upper-limb support. The profiles of the subjects are shown in Table 1. The Epidemiologic Research Ethics Committee of Gunma University Faculty of Medicine approved this study (No. 27-38), and informed consent was obtained from each participant.

The STW task was performed under conditions based on those reported by Malouin²¹). Subjects sat on a chair without a back support or armrests and with a seat height standardized to 100% of leg length. Subjects were required to fold their arms across their chest and to stand up from the chair and walk toward a target placed 2 m in front of the chair. They were required to keep their arms folded across their chest throughout the task. The task was performed at two speeds: comfortable and maximum. Each trial was recorded using an electrostatic-capacity type three-axial acceleration sensor (MVP-RF8-HC, MicroStone, Nagano, Japan), a motion capture system (MA3000, Anima, Tokyo, Japan) with six infrared cameras, and a foot pressure sensing system (Walk Way, Anima). The sampling frequency was 100 Hz. The acceleration sensor was attached between the L3 and L4 vertebrae⁹) with an elastic band and was oriented to measure the anterior-posterior axis, medial-lateral axis and vertical axis. In this study, only anterior-posterior data were analyzed. Reflective markers were attached to the acromion, anterior superior iliac spine, greater trochanter, knee joint, lateral malleolus and head of the fifth metatarsal on both sides of the body. Acceleration and kinematic data were filtered using a zero-phase low-pass filter with a cut-off frequency of 8 Hz. A typical acceleration waveform and definitions of the events during the task are shown in Fig. 1. The events analyzed from the acceleration waveform were onset of the STW task, first peak and second peak. The definitions of each event were the same as in our previous study²⁴). The onset of the STW task in the acceleration waveform was defined as the point at which the acceleration exceeded two standard deviations of the mean of data from the 3-s stationary period. The onset of the STW task in the motion capture system data was the initiation of forward motion of the acromion marker. The first peak

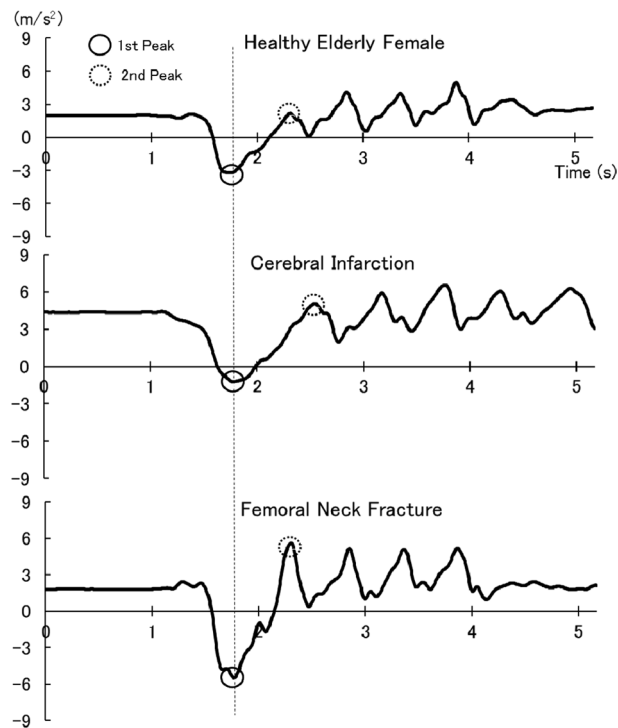


Fig. 2. Examples of accelerometer waveforms recorded from a healthy participant and participants with notable medical history. All waveforms have the same characteristics.

in the acceleration waveform was the first local minimum reached after onset. The timing of the first peak was compared to the timing of maximum trunk inclination recorded by the motion capture system. The second peak in the acceleration waveform was defined as the positive peak following the first peak and followed by rapid negative acceleration. The timing of the second peak was compared to the timing of first heel strike recorded by the foot pressure sensing system. For each comparison, a Bland-Altman plot was generated by plotting the difference between the two measures against the mean of the two measures to provide a visual representation of heteroscedasticity. The existence of systematic bias was also examined.

The events identified from the acceleration waveform were used to define the phases of the task. Phase 1 was from the onset of the STW task to the first peak and phase 2 was from the first peak to the second peak. The durations of these two phases were used as independent variables in a simple linear regression analysis. The FI, which corresponds to the change in the body forward momentum, was the dependent variable in the regression analysis. In all statistical analyses, one trial was used for each speed condition. All statistical analyses were performed using SPSS statistics 22.0 (IBM, Armonk, NY, USA). Statistical significance was set at $p < 0.05$.

RESULTS

Some examples of accelerometer waveforms recorded from a healthy subject and subjects with notable medical history are shown in Fig. 2. The magnitude of acceleration was variable, but the characteristics of the waveform were similar.

Differences in the timing of events calculated using the accelerometer and reference data are shown in Table 2. In each speed condition, the differences in the onset of the STW task identified from the accelerometer and the motion analysis system data were quite small. The first peak appeared simultaneously with maximum trunk inclination and the second peak occurred simultaneously with first heel strike. According to the Bland-Altman analysis, there was no fixed bias or proportional bias for any of the three events. The results of a simple regression analysis to estimate the timing of events from the acceleration data are shown in Table 3. In each speed condition, all three events were estimated by a significant regression equation. The coefficient of determination ranged from 0.500 to 0.998.

The FI, the duration of both phases and the results of a simple linear regression analysis to estimate FI are shown in Table 4. In the comfortable speed condition, the duration of the phase 1, phase 2, and the total (phase 1 + phase 2) were respectively 0.95 ± 0.27 , 0.88 ± 0.34 , and 1.87 ± 0.49 . Similarly, in the maximum speed condition, 0.99 ± 0.48 , 0.62 ± 0.18 , and 1.61 ± 0.52 . In both speed conditions, significant regression equations estimating FI were constructed from the duration of phase 2. The coefficient of determination was 0.757 in the comfortable speed condition and 0.731 in the maximum speed condition.

Table 2. Difference in event timing measured by two systems

Speed condition	Onset of STW Accelerometer-Motion analysis system		1st peak-Maximum trunk inclination		2nd peak-Heel strike	
	mean ± SD (s)	95%CI	mean ± SD (s)	95%CI	mean ± SD (s)	95%CI
Comfortable	0.10 ± 0.35	-0.08-0.28	0.02 ± 0.06	-0.02-0.05	-0.01 ± 0.07	-0.05-0.02
Maximum	-0.13 ± 0.35	-0.31-0.06	-0.02 ± 0.07	-0.06-0.02	-0.02 ± 0.05	-0.04-0.01

STW: sit-to-walk task; SD: standard deviation; CI: confidence interval

1st peak: The first negative peak in acceleration.

Maximum trunk inclination: Recorded by the motion capture system.

2nd peak: The last positive peak followed by rapid negative acceleration.

Heel strike: Recorded by the foot pressure sensing system.

Table 3. Results of single regression analysis to predict event

Speed condition	Regression equation	R ²	
Comfortable	Onset=0.568+0.822×(timing of onset defined by acceleration)	0.500	*
	Maximum trunk inclination=0.025+0.998×(timing of 1st peak)	0.972	**
	Heel strike=0.330+0.937×(timing of 2nd peak)	0.913	**
Maximum	Onset=0.001+0.979×(timing of onset defined by acceleration)	0.892	**
	Maximum trunk inclination=0.063+0.992×(timing of 1st peak)	0.997	**
	Heel strike=0.071+0.994×(timing of 2nd peak)	0.998	**

**p<0.0001, *p<0.001

Table 4. Results of FI and single regression analysis to predict FI from the duration of each phase

FI	mean ± SD (%)		
Comfortable	53.48 ± 34.04		
Maximum	70.25 ± 28.03		
Regression analysis	mean ± SD (s)		R ²
Phase 1			
Comfortable	0.95 ± 0.27	FI=93.24 – 41.54×(Phase 1)	0.109
Maximum	0.99 ± 0.48	FI=80.40 – 10.26×(Phase 1)	0.031
Phase 2			
Comfortable	0.88 ± 0.34	FI=128.73 – 85.83×(Phase 2)	0.757 **
Maximum	0.62 ± 0.18	FI=153.24 – 134.12×(Phase 2)	0.731 **
Phase 1+2			
Comfortable	1.87 ± 0.49	FI=146.61 – 49.83×(Phase 1+2)	0.510 *
Maximum	1.61 ± 0.52	FI=109.72 – 24.55×(Phase 1+2)	0.208

**p<0.0001, *p<0.001

FI: fluidity index, SD: standard deviation

DISCUSSION

The subjects in this study were community-dwelling elderly persons, including patients with long-term cerebral infarction, spinal disease, osteoarthritis or fracture of the lower extremity. However, subjects only had mild disability. The FI of these subjects tended to be lower than that reported in healthy elderly persons²⁵).

The acceleration waveforms recorded from the subjects in the current study had similar characteristics to those previously recorded from healthy young adults²⁴). Therefore, the same definition of events was used. The timings of all events measured by the accelerometer agreed sufficiently with that measured by the motion analysis system. These results demonstrate the concurrent validity of the accelerometer method.

The duration of phase 2 was the best predictor of FI in both speed conditions. This is the same as in healthy young

adults²⁴). Phase 2 is the transitional phase covering sit-to-stand to gait initiation. The shorter the duration of this phase, the higher the fluidity of the movement.

Persons with a history of falls showed a delay of gait initiation²⁶), i.e., lower fluidity. Fluidity during the STW task is related to falls and depends on locomotor coordination and balance^{19, 22}). Qualitative evaluation of the STW motion focused on fluidity may be able to predict falls. Using an accelerometer to quantify the STW motion in a community setting is meaningful. Before this study, it was unclear whether the acceleration waveforms of elderly persons or patient populations would be the same as those of healthy younger adults, and whether the duration of either phase would predict FI in elderly persons. The results of this study answer this question and indicate that it is possible to quantify fluidity outside the laboratory setting.

A limitation of this study is that the subjects had only mild disability. In persons with more severe disability, particularly ataxia, the waveform may be quite different. Therefore, further verification is needed before this method is used in the clinical or community setting.

REFERENCES

- 1) Weiss A, Herman T, Plotnik M, et al.: Can an accelerometer enhance the utility of the Timed Up & Go Test when evaluating patients with Parkinson's disease? *Med Eng Phys*, 2010, 32: 119–125. [[Medline](#)] [[CrossRef](#)]
- 2) Hartmann A, Murer K, de Bie RA, et al.: Reproducibility of spatio-temporal gait parameters under different conditions in older adults using a trunk tri-axial accelerometer system. *Gait Posture*, 2009, 30: 351–355. [[Medline](#)] [[CrossRef](#)]
- 3) Weiss A, Herman T, Plotnik M, et al.: An instrumented timed up and go: the added value of an accelerometer for identifying fall risk in idiopathic fallers. *Physiol Meas*, 2011, 32: 2003–2018. [[Medline](#)] [[CrossRef](#)]
- 4) Ganea R, Paraschiv-Ionescu A, Büla C, et al.: Multi-parametric evaluation of sit-to-stand and stand-to-sit transitions in elderly people. *Med Eng Phys*, 2011, 33: 1086–1093. [[Medline](#)] [[CrossRef](#)]
- 5) Moe-Nilssen R: Test-retest reliability of trunk accelerometry during standing and walking. *Arch Phys Med Rehabil*, 1998, 79: 1377–1385. [[Medline](#)] [[CrossRef](#)]
- 6) Zijlstra W, Hof AL: Assessment of spatio-temporal gait parameters from trunk accelerations during human walking. *Gait Posture*, 2003, 18: 1–10. [[Medline](#)] [[CrossRef](#)]
- 7) Zijlstra W: Assessment of spatio-temporal parameters during unconstrained walking. *Eur J Appl Physiol*, 2004, 92: 39–44. [[Medline](#)] [[CrossRef](#)]
- 8) Hartmann A, Luzzi S, Murer K, et al.: Concurrent validity of a trunk tri-axial accelerometer system for gait analysis in older adults. *Gait Posture*, 2009, 29: 444–448. [[Medline](#)] [[CrossRef](#)]
- 9) Osaka H, Watanabe S, Fujita D, et al.: Appropriate location of an accelerometer for gait analysis: a comparative study based on cross-correlation. *Rigakuryoho Kagaku*, 2011, 26: 785–789 (in Japanese). [[CrossRef](#)]
- 10) Janssen WG, Bussmann JB, Horemans HL, et al.: Validity of accelerometry in assessing the duration of the sit-to-stand movement. *Med Biol Eng Comput*, 2008, 46: 879–887. [[Medline](#)] [[CrossRef](#)]
- 11) Kitagawa N, Ogiwara N: Estimation of foot trajectory during human walking by a wearable inertial measurement unit mounted to the foot. *Gait Posture*, 2016, 45: 110–114. [[Medline](#)] [[CrossRef](#)]
- 12) Mellone S, Tacconi C, Chiari L: Validity of a Smartphone-based instrumented Timed Up and Go. *Gait Posture*, 2012, 36: 163–165. [[Medline](#)] [[CrossRef](#)]
- 13) Mercant AG, Vargas CA: Differences in trunk kinematic between frail and nonfrail elderly persons during turn transition based on a smartphone inertial sensor. *BioMed Research International*, 2013, Article ID 279197.
- 14) Yodpigit N, Songwongamart C, Tavichaiyuth N: Implementation of a smart phone for motion analysis. *Biomed Sci Instrum*, 2015, 51: 315–322. [[Medline](#)]
- 15) Duncan MJ, Vandelandotte C, Trost SG, et al.: Balanced: a randomised trial examining the efficacy of two self-monitoring methods for an app-based multi-behaviour intervention to improve physical activity, sitting and sleep in adults. *BMC Public Health*, 2016, 16: 670. [[Medline](#)] [[CrossRef](#)]
- 16) Asakura T, Usuda S, Shirakura K: Determinations of fluidity in the sit-to-walk task performed by healthy adults. *Rigakuryoho Kagaku*, 2011, 26: 251–254 (in Japanese). [[CrossRef](#)]
- 17) Asakura T, Usuda S: Effects of directional change on postural adjustments during the sit-to-walk task. *J Phys Ther Sci*, 2013, 25: 1377–1381. [[Medline](#)] [[CrossRef](#)]
- 18) Magnan A, McFayden BJ, St-Vincent G: Modification of sit-to-stand task with the addition of gait initiation. *Gait Posture*, 1996, 4: 232–241. [[CrossRef](#)]
- 19) Kerr A, Durward B, Kerr KM: Defining phases for the sit-to-walk movement. *Clin Biomech (Bristol, Avon)*, 2004, 19: 385–390. [[Medline](#)] [[CrossRef](#)]
- 20) Kerr A, Rafferty D, Kerr KM, et al.: Timing phases of the sit-to-walk movement: validity of a clinical test. *Gait Posture*, 2007, 26: 11–16. [[Medline](#)] [[CrossRef](#)]
- 21) Malouin F, McFadyen B, Dion L, et al.: A fluidity scale for evaluating the motor strategy of the rise-to-walk task after stroke. *Clin Rehabil*, 2003, 17: 674–684. [[Medline](#)] [[CrossRef](#)]
- 22) Dion L, Malouin F, McFadyen B, et al.: Assessing mobility and locomotor coordination after stroke with the rise-to-walk task. *Neurorehabil Neural Repair*, 2003, 17: 83–92. [[Medline](#)] [[CrossRef](#)]
- 23) Kouta M, Shinkoda K: Differences in biomechanical characteristics of sit-to-walk motion between younger and elderly males dwelling in the community. *J Phys Ther Sci*, 2008, 20: 185–189. [[CrossRef](#)]
- 24) Asakura T, Hagiwara H, Miyazawa Y, et al.: An accelerometer-based method for estimating fluidity in the sit-to-walk task. *J Phys Ther Sci*, 2015, 27: 3565–3569. [[Medline](#)] [[CrossRef](#)]
- 25) Osada Y, Yamamoto S, Fuchi M, et al.: Sit-to-walk task in hemiplegic stroke patients: relationship between movement fluidity and the motor strategy in initial contact. *J Jpn Phys Ther Assoc*, 2015, 18: 7–14. [[Medline](#)] [[CrossRef](#)]
- 26) Kouta M, Shinkoda K: Relationship between biomechanics of sit-to-walk motion and physical functions or fall experiences of elderly people living at home. *Rigakuryoho Kagaku*, 2008, 23: 125–131 (in Japanese). [[CrossRef](#)]