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Original Article

The relationship between acceleration in sit-to-stand and falls in community-dwelling older adults: cross-sectional study

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Abstract. [Purpose] This study aimed to determine the relationship between acceleration parameters in the sit-to-stand (STS) movement and falls, and the strength of the association between acceleration in STS movements and falls in older adults. [Participants and Methods] In total, 330 older adults were included. Four acceleration parameters were measured in STS movement: maximum acceleration (MA), velocity (MV), power (MP), and stand-up time (ST). For the conventional STS tests, 5 times STS test (5xSTS) and ground reaction force (maximal rate of force development per body weight: RFD/w, peak reaction force per body weight: F/w, chair-rise time: T) were measured. Poisson regression analysis adjusted for confounding factors was used. [Results] In the model adjusted for confounders, significant associations were observed among MV (Prevalence ratio (PR): 0.75; 95% confidence interval (CI): 0.58–0.98), MP (PR: 0.67; 95% Cl: 0.68–0.93), RFD/w (PR: 0.70; 95% Cl: 0.56–0.87), and T (PR: 1.14; 95% Cl: 1.05–1.24). [Conclusion] Among the acceleration parameters, MP was most strongly associated with falls and was considered the most useful parameter for evaluation. In addition, comparisons with the conventional chair rise tests suggested that MP was stronger than the 5xSTS test and may be equally related to the RFD/w.
Key words: Acceleration parameter, Chair-rise, Fall history

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INTRODUCTION

Falls in older adults cause a variety of events, including fear of falling[1)], decreased physical activity[2, 3)], admission to the facility[4)], and death[5)]. Therefore, fall prevention measures are important in older adults. Surveys of risk factors for falls, conducted as part of fall prevention, have reported associations with various factors, such as reaction time, poor balance, and muscle weakness[6)]. Moreover, guidelines for fall prevention advocate the need for early assessment of fall risk[7)]. Functional performance tests such as walking and standing are used as fall risk screening tools in clinical settings[8, 9)].

Since rising from a sitting to a standing position is a pre-stress movement before moving to standing or walking[10)] and requires a great deal of muscular exertion[11)], sit-to-stand (STS) tests have been often used to assess the risk of falling. Typical performance tests using STS movements include recording the time required to perform a given number of repetitions (5 times STS test: 5xSTS)[12)] or the number of repetitions that can be performed within a given time (30-second STS test)[13)]. However, such stopwatch-based methods are easily influenced by the evaluator's experience and reaction time[14)]; therefore, a more objective evaluation method is required.

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Recently, small sensors such as accelerometers (acceleration, angular velocity, etc.) have been developed, and have been employed in physical function measurement methods[15]. The basic flow of the measurement is to have the individual perform physical fitness tests (standing and walking movements) while wearing the sensor and evaluate the results using the parameters obtained from the sensor. This sensor-based measurement can objectively obtain not only completion times, but also more multifaceted information (maximum acceleration, maximum velocity, maximum power, etc.)[16, 17]. In addition, the device is small, portable, and inexpensive[18], making it highly versatile and easy to use in clinical practice.

Several studies have examined the association between acceleration parameters of STS movements and falls. Doheny et al. compared acceleration parameters (temporal parameter) of STS movements in 40 older adults who experienced fall and those who did not and reported that fallers showed higher values than non-fallers[19]. In another study, the same validation was conducted in 94 older participants, and fallers showed significantly poorer values of acceleration parameters (temporal parameter and velocity) than non-fallers[20].

However, to the best of our knowledge, most studies reported to date have been laboratory-based verifications, and the findings are based on a small number of individuals with low generalizability. In addition, the analysis methods are limited by sample size, while majority of the analyses were not adjusted for potential confounders (e.g., gender and age) and have been unable to clarify the independent effects of acceleration parameters in STS movements. Therefore, to accurately investigate the relationship between acceleration parameters in STS movements and falls, we suggest that a larger sample size is required with adjustment for basic factors. In addition, most previous studies employed 5xSTS as chair rise test[19, 20]. Because it has been reported that continuous standing is burdensome for older adults and that some are unable to perform the test[21], a chair rise test that reduces the burden on older adults is desirable. However, a chair rise test using a small sensor can quantify movement during operation with only one rise, without continuous operation. Therefore, some studies have conducted non-continuous STS tests and examined the reliability of acceleration parameters in STS movements and their relationship with physical function[21]. For ease of application in the field, this study will employ a chair rise test that does not require continuous movement using an accelerometer. Thus, by examining the relationship between acceleration parameters and falls during a noncontinuous STS test, we expect to increase the versatility of acceleration parameters in STS movements as a field test.

One such non-consecutive STS test is a performance test that uses ground reaction force parameters. In this method, ground reaction force parameters are extracted from the ground reaction force waveform obtained when the participant rises from a chair with maximum effort, and an evaluation is performed based on these parameters. Various studies have been conducted to clarify the reliability and validity of ground reaction force parameters[22]. The relationship between the ground reaction force and falls has been examined both cross-sectionally and longitudinally[22, 23], with confirmed good validity. In this study, we consider the ground reaction force parameter as a validity criterion. Therefore, by comparing the strength of its association with acceleration during chair rise, we will be able to examine the usefulness of the acceleration parameter.

The purpose of this study was to determine the relationship between acceleration during non-continuous STS tests and falls among the older adults by randomly selected from the Basic Resident Registers to increase the representativeness and sample size of the older adults living in the community. In addition, a comparison will be made between the strength of the association between the conventional chair rise test (5xSTS test and ground reaction force) and the acceleration during chair rise used in this study and falls. Furthermore, since it has been reported[20] that in a comparison of acceleration parameters in STS movements in fallers and non-fallers, during standing up is more strongly related than during sitting down, it is thought that good acceleration parameters during the non-continuous STS test employed in this study will also reduce the risk of falling.

PARTICIPANTS AND METHODS

This study used data from the Kasama study, an open cohort study conducted annually since 2009 in Kasama City, Ibaraki Prefecture (population 72,727, area 240.4 km^2, ratio of older adults: 32.8%)[24]. The study included participants aged 65–85 years who were randomly selected from the basic registry network system and were not residing in a nursing home. Past participants were followed-up, excluding those who had been certified as needing long-term care, died, or moved away, and a random sample of new participants aged ≥65 years was added each year. On average, approximately 1,730 (1,664–1,799) people received invitations between 2021 and 2022, with an average of 226 (216–236) persons/year participating in the study. The datasets used in this study were generated from the 2021–2022 measurements. Written informed consent was obtained from all the participants. This study was approved by the Ethics Committee of the University of Tsukuba (Ref No., Tai 30-5).

Of the 452 participants in this study, 110 participated for two consecutive years and data for 2021 were used; therefore, 342 participants were included in the study. Of them, 12 participants were excluded from the analysis, including those who did not participate in the physical fitness test for physical reasons (n=2), those who required assistance in standing up (n=9), and those who had missing questionnaire items (n=1). Finally, a total of 330 participants were analyzed.

After the standing movement pattern was explained, the participants sat in a standard-height (40 cm) chair, legs shoulder-width apart, trunk extended in a straight vertical line, and ankles held at 90° on a force plate (BM-220 zaRitz TANITA, Tokyo, Japan). The participant rose as quickly as possible from the chair with arms folded, stood still for approximately 2 s, and sat down again. The triaxial accelerometer (TANITA) was attached to the participant's lower back; the sampling frequency of the triaxial accelerometer (± 8 G) was 128 Hz.

MATLAB (The MathWorks, Inc., Natick, MA, USA; version 9.22) was used for data analyses. First, the 3-axis accelerometer data were transferred to a notebook PC and a low-pass Butterworth filter (cutoff frequency=6 Hz) was applied. Four parameters were collected based on previous studies[25–27]. To obtain gravitational acceleration when the participant was stationary, the following corrections were made:

Acorr (relative acceleration) = Ameans (actual acceleration) − Aref (reference) + 9.81

where Acorr is the corrected acceleration, Ameas is the measured acceleration, and Aref is the reference value of the acceleration measured 1 s prior to the STS movement (stationary).

The measured parameters based on previous studies[25–27] were:

1. Stand-up time (ST): Referring to previous studies[25], the start of the STS movement was estimated from the derivative value of the acceleration. The end of the STS movement was the first sample when the norm acceleration reached the gravity level after the negative acceleration peak.

2. Maximum acceleration (MA): This was the highest acceleration during the STS movements.

3. Maximum velocity (MV): This was the maximum velocity during STS movements calculated by numerically integrating the acceleration. The velocity was estimated by assuming that the velocity at the start of the rise was 0 m/s.

4. Maximum power (MP): This was the peak power during the STS movements. First, F was calculated by fitting the formula: F=m • Acorr, where m is the body weight. Next, power (P) was estimated by multiplying force (F) by velocity: P=F • v. This corresponds to the maximum value obtained by multiplying the solid and dotted lines in Fig. 1 (bottom) by body weight.

The ground reaction force was measured using the parameters obtained from the force plate (BM-220, zaRitz TANITA) during the STS measurement described above. The sampling period of this instrument was 80 Hz, and the vertical ground reaction force (kgf) during the STS movements was recorded. Three parameters, F/w (peak reaction force per body weight), RFD/w (maximal rate of force development per body weight), and T (chair-rise time), were calculated using methods reported in previous study[22].

The participants were asked to move from a sitting to a standing position five times as quickly as possible; the shortest time required to complete the task in two trials was used in the analysis[28].

The number of falls was assessed using a questionnaire. Participants who had experienced falls at least once in the past year were defined as fallers and those who had not were defined as non-fallers.

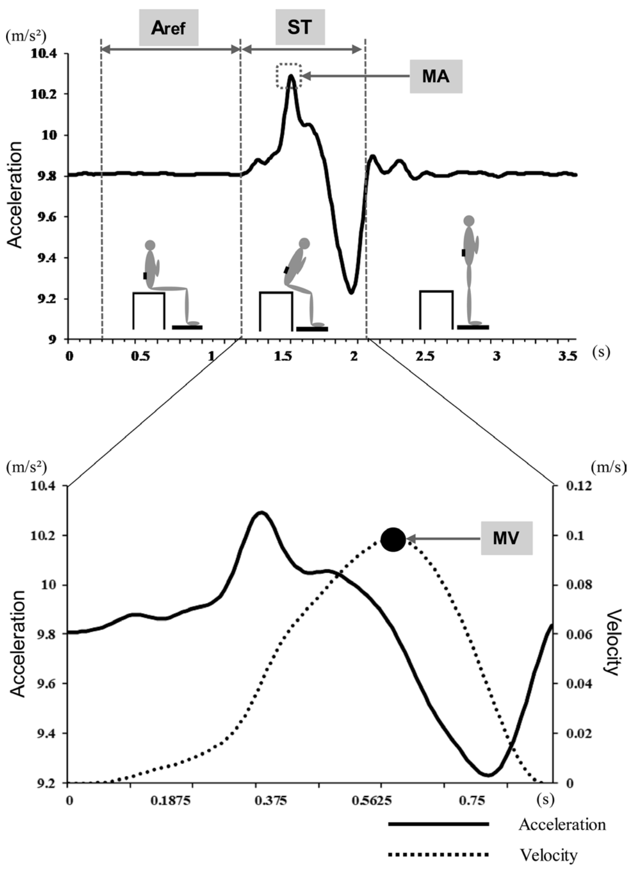

Fig. 1. Acceleration parameters.
Aref: acceleration reference; ST: stand up time; MA: maximum acceleration; MV: maximum velocity.

We also collected the following information for using as covariate referencing previous study[22]: Age, gender, body mass index (BMI), lower back pain and lower-limb pain. The BMI was calculated by dividing patient weight in kilograms by the square of their height in meters (kg/m^2), and classified into underweight (BMI <18.5), normal weight (18.5≤ BMI <25.0), and obesity (BMI ≥25.0). Back pain and lower limb pain were each investigated using a questionnaire.

Unpaired t-tests and χ^2 tests were performed to compare basic attributes between fallers and non-fallers. A Poisson regression analysis was performed with the presence or absence of falls as the objective variables, acceleration parameter as the explanatory variables, ground reaction force parameter as the comparison parameter, and five chair-rise time as separate inputs to examine the association between the acceleration parameter and history of falls while standing. In this study, the proportion of patients who had experienced falls was more than 10%. Logistic regression analysis to calculate odds ratios may lead to overestimation[34]. Therefore, Poisson regression analysis was performed. Each parameter was standardized, with 1 SD as one unit. The prevalence ratio (PR) and 95% confidence interval (CI) for each parameter were calculated. For the cross-sectional study, three models were created: a model with no adjustment parameters (Crude model); Model 1 with gender and age added as adjustment parameters; and Model 2 with BMI, presence of back pain, and presence of lower extremity pain added to Model 1. All analyses were performed using IBM SPSS (version 26.0; IBM Corp., Armonk, NY, USA), with a significance level of 5%.

RESULTS

Table 1 presents the basic demographic characteristics of the participants. The mean age was 75.5 years; 184 (55.8%) were female, and of the 330 participants, 48 (14.5%) reported falling.

Table 2 shows the association between history of falls and the STS test. In the Crude model, significant associations were found for all items ($p<0.05$), with better values for all parameters resulting in a lower risk of falling. In Models 2 and 3, significant associations were found for MV, MP, RFD/w, and T. The PR indicating the strength of the association was lowest for MP at 0.67 (95% Cl: 0.68 to 0.93), followed by RFD/w at 0.70 (95% Cl: 0.56 to −0.87), MV at 0.75 (95% Cl: 0.58 to 0.98) and T at 1.14 (95% Cl: 1.05 to 1.24).

DISCUSSION

This study clarified the relationship between acceleration in STS movements and falls using a triaxial accelerometer. The strength of the relationship between the conventional STS test and falls was also compared by examining the relationship between acceleration parameters and falls. The results showed that acceleration was significantly associated with falls, which is consistent with our hypothesis. In the conventional STS test, significant associations were confirmed for the ground reaction force parameters RFD/w and T, but not for the 5xSTS test. These results indicate that the acceleration parameter in STS movements may be more strongly associated with falling than that in the conventional stopwatch-based 5xSTS test.

Previously, the association between past fall experiences and acceleration parameters in STS movements was only examined in a small number of older participants (40–94 persons)[19, 20]. In contrast, the present study included 330 older participants and found that better acceleration parameters, such as MV and MP, reduced the risk of falling, even after adjusting for basic attributes and other factors. Shukla et al.[26] found that the acceleration parameters during STS movements that differed most between fallers and non-fallers were velocity and power and reported a significant association between acceleration parameters and falls. Despite differences in analysis methods, the present study also showed significant associations between acceleration parameters velocity and power during STS movements and falls. Regterschot et al.[29] conducted an 8-week

Table 1. Characteristics of participants (n=330)

	All (n=330)
Age (years) mean ± SD	75.5 ± 5.4
Percentage of females	55.8% (184)
Height (cm) mean ± SD	156.7 ± 8.1
Weight (kg) mean ± SD	56.7 ± 10.4
BMI (kg/m^2)	
<18.5	8.2% (27)
18.5–24.9	66.7% (220)
≥25	25.2% (83)
Lower back pain, yes	26.4% (87)
Lower limb pain, yes	14.5% (48)
History of any falls, yes	14.5% (48)

SD: standard deviation; BMI: body mass index.

Table 2. Association of chair-rise tests with history of falls

	Unit	Crude model	Model 1	Model 2
		PR (95% CI)	PR (95% CI)	PR (95% CI)
Acceleration parameters				
MA	(1SD)	**0.69* (0.50–0.97)**	0.78 (0.58–1.06)	0.80 (0.60–1.07)
MV	(1SD)	**0.63* (0.49–0.80)**	**0.72* (0.55–0.95)**	**0.75* (0.58–0.98)**
MP	(1SD)	**0.56* (0.42–0.75)**	**0.65* (0.46–0.92)**	**0.67* (0.68–0.93)**
ST	(1SD)	**1.27* (1.02–1.58)**	1.21 (0.98–1.50)	1.18 (0.97–1.43)
Ground reaction force parameters				
F/w	(1SD)	**0.69* (0.54–0.88)**	0.79 (0.58–1.06)	0.81 (0.60–1.10)
RFD/w	(1SD)	**0.63* (0.51–0.78)**	**0.69* (0.56–0.86)**	**0.70* (0.56–0.87)**
T	(1SD)	**1.17* (1.05–1.30)**	**1.12* (1.03–1.21)**	**1.14* (1.05–1.24)**
Conventional stopwatch-based method				
Five-times sit-to-stand test	(1SD)	**1.30* (1.04–1.63)**	1.21 (0.96–1.54)	1.18 (0.92–1.51)

n=330.
*$p<0.05$.
Bold represent significant association between chair-rise test and history of falls.
PR: prevalence ratio; CI: confidence interval; Model1: adjusted for age and gender; Model2: body mass index, lower back pain and lower-limb pain, in addition to Model1; MA: maximum acceleration; MV: maximum velocity; MP: maximum power; ST: Stand-up time; F: peak reaction force; RFD: maximal rate of force development; T: chair-rise time; w: body weight.; SD: standard deviation.

exercise program in elderly subjects and evaluated their performance in chair-rising movements before and after the intervention, and found high sensitivity in power and speed using sensors, suggesting that these parameters are useful in detecting fall risk. Similarly, MP and MV showed significant associations even after adjusting for potential confounding factors in the present study. Therefore, A combination of programs aimed at strengthening lower extremity muscles and improving balance may reduce the risk of falls. On the other hand, the temporal parameter ST showed a significant association in the Crude model but not in models 1 and 2, whereas Ejupi et al.[20] found a weaker association for the temporal parameter than for the kinematic parameter (velocity) when comparing the acceleration parameters of STS movements in fallers and non-fallers. This suggests the importance of using kinematic and kinetic parameters during the rising motion rather than evaluating time units such as the time of completion of the motion.

In addition, the results were compared with those of conventional STS tests (ground reaction force and 5xSTS test). For the ground reaction force parameter, RFD/w and T showed significant associations, whereas for the 5xSTS test, although significant in the crude model, they showed no significant associations after adjustment. Given these results, the acceleration parameter for chair rise time appears to be associated with falls as strongly as the ground reaction force measurement, more so than the 5xSTS test. 5xSTS test was not significantly associated with the occurrence of falls[30] and no association with lower extremity muscle strength, which has been reported to be associated with falls, and was comparable or less than that of ground reaction force parameters[31]. Therefore, the association between 5xSTS test and falls may have been weaker than for acceleration or ground reaction force. Several studies have reported significant associations between falls and the ground reaction force parameter[22, 32], and we consider this study as a valid criterion for fall risk assessment in older adults. Moreover, as the association between chair-rise acceleration and falls was as strong as that of such measures, it may provide valuable data for developing acceleration parameters for field tests.

The strength of this study is that it examined the relationship between acceleration in STS movements and falls using a more representative and larger sample size of community-dwelling older adults than previous studies. However, this study had several limitations. First, as the study included participants in measurement sessions, they tended to be in a high state of health. Therefore, it should be noted that the findings are not necessarily applicable to all community-dwelling older adults. Second, because the study design was cross-sectional study, a causal relationship between acceleration during chair rise and falls could not be determined. In the future, we believe that the results can be better applied to the field by using longitudinal data to evaluate the risk of falls by providing cutoff values to determine the occurrence of prospective falls. Finally, in this study, falls were investigated using a questionnaire, and participants were divided into groups according to whether they had fallen more than once, regardless of the number of falls or injuries caused by falls. However, it has been reported that lower limb muscle weakness has a more pronounced effect on the occurrence of multiple falls than on singular falls[33]. Additionally, the occurrence of a single fall was not expected to be influenced by inattention or environmental factors. Therefore, future reexamination of the occurrence of multiple falls as an outcome is warranted.

In conclusion, this cross-sectional study was conducted to determine the association between acceleration and falls during STS movement. The results showed that all acceleration parameters are significantly associated in the crude model.

However, after adjusting for basic attributes, significant associations were found for MV and MP. Of these, MP was most strongly associated with falls and was considered the most useful parameter for evaluation. In addition, a comparison with the conventional chair rise test suggested that it may have an equal association with the ground reaction force parameter, which was stronger than the 5xSTS test.

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Conflicts of interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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