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Original Article

Ground Reaction Force in Sit-to-stand Movement Reflects Lower Limb Muscle Strength and Power in Community-dwelling Older Adults☆

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SUMMARY

Background: Ground reaction force parameters in a sit-to-stand (STS) movement can be used to evaluate lower extremity function. Few reports, however, are available on whether the ground reaction force parameters in an STS movement reflect dynamic knee and ankle strength or power. The aims of this study were to examine associations among ground reaction force parameters in an STS movement and isokinetic knee and ankle strength and power in healthy older adults, and to compare associations with the five-times STS test.
Methods: The following five ground reaction force parameters were measured in 19 men and 28 women: peak reaction force, two rate of force development (RFD) parameters and two time-related parameters.
Results: RFD (Δ90 ms)/body weight correlated significantly with average isokinetic knee extension/flexion power in both sexes (partial-r = 0.39–0.54) and average ankle plantar flexion and dorsiflexion power (partial-r = 0.50 and partial-r = 0.49, respectively), in women. No isokinetic parameters were significantly related to the five-times STS test.
Conclusion: Ground reaction force parameters in an STS movement can accurately reflect the dynamic strength and power in the lower limbs, which is approximately equal to or better than the strength and power reflected by the five-times STS test.

1. Introduction

Research has firmly established the importance of lower limb muscle strength during a sit-to-stand (STS) movement[1,2]. In the clinical setting of preventive nursing care for older adults, field tests of the STS movement are frequently used to indirectly evaluate the lower limb muscle strength. However, other physiological and psychological factors may also affect the execution of an STS movement, which is a daily functional movement. The STS test considers these factors and can be tailored according to the daily lifestyle of an elderly person, which sets it apart from other tests, e.g., the isokinetic test, that directly evaluate monoarticular muscle strength. However, to demonstrate the validity of the STS test, a correlation between the results of the STS test and the lower limb muscle strength is necessary, along with determination of the extent to which these results reflect such values.

The STS movement is tested either by recording the time required for a certain number of repetitions, e.g., five-times STS test[2,3], or the number of repetitions performed within a specified time frame, e.g., 30-second chair-stand test[2,4]. However, these tests do not always reflect leg muscle function because they also involve other factors, such as general endurance[5].

Recent reports[6,7] have revealed the vertical ground reaction force parameters in an STS movement to be useful for evaluating lower limb muscle strength and power in older adults. The benefits of this method are: (1) assessment of the force output during any activity of daily living (i.e., complex motor tasks), which may be more functional than measuring the muscle strength or power of a single joint; (2) ability to measure a person who is able to perform only a few STS movements; (3) relative ease of transporting the measurement instrument (simple force platform); and (4) the direct measurement of

☆ Conflicts of interest: All contributing authors declare that they have no conflicts of interest.

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the force output in kgf using the force platform. This approach can bring the benefits of evaluating lower limb strength and power into the clinical setting of preventive nursing care. The ground reaction force parameters have good test-retest reliability (intraclass correlation coefficients: 0.70–0.95), and they significantly relate to isometric knee extension strength in community-dwelling older adults[7]. However, to the best of our knowledge, the associations between the ground reaction force parameters and dynamic knee strength and power, which play a more important role when performing activities of daily living[8], have not been reported. Moreover, although strength of the muscles around the ankle joint is important to decrease fall risk[9], the relationship between ground reaction force parameters and strength and power output by these has not been discussed. A kinematic study of the STS movement[10] suggests that ankle dorsiflexion strength is essential during the flexion-momentum phase (Phase I), when the body weight is shifted from the buttocks to feet immediately after movement initiation. Knee extension strength is essential during the momentum transfer phase (Phase II), when the body weight is shifted from the chair to the feet and the extension phase (Phase III), when maximum knee extensor velocity is achieved. In addition, the force output at the feet and lower limbs (i.e., around the ankle joint), which were proximally positioned to the force platform, may have an important effect on ground reaction force parameters.

This study aimed to examine associations of ground reaction force parameters of an STS movement with isokinetic knee and ankle strength and power in healthy older adults and compare these with the five-times STS results. We hypothesized that ground reaction force parameters, which can directly reflect the force output while more important phases require muscular exertion at the knees and ankles to complete the STS movements, are more significantly associated with dynamic strength and power in the lower limbs than the five-times STS test, which is an indirect time-based evaluation method.

2. Materials and methods

2.1. Participants

We used the baseline data recorded from individuals who participated in an exercise program at our university. Community-dwelling healthy older adults, aged 65–75 years, were recruited by means of advertisements placed in the local newspaper. The Ethics Board of the University of Tsukuba in Japan approved the study. Of the 75 respondents, 17 were excluded after telephone interviews because of lack of transportation to our university, inability to attend the study orientation, dependent living status, and having any physiological disorder that precluded strenuous exercise. Of 51 randomly-chosen participants, four withdrew. Finally, 19 men and 28 women gave written informed consent and participated in the study (Fig. 1).

2.2. Testing protocol

Testing was performed on 2 days, with a 7-day interval. On Day 1, we measured ground reaction force of the STS movement and the

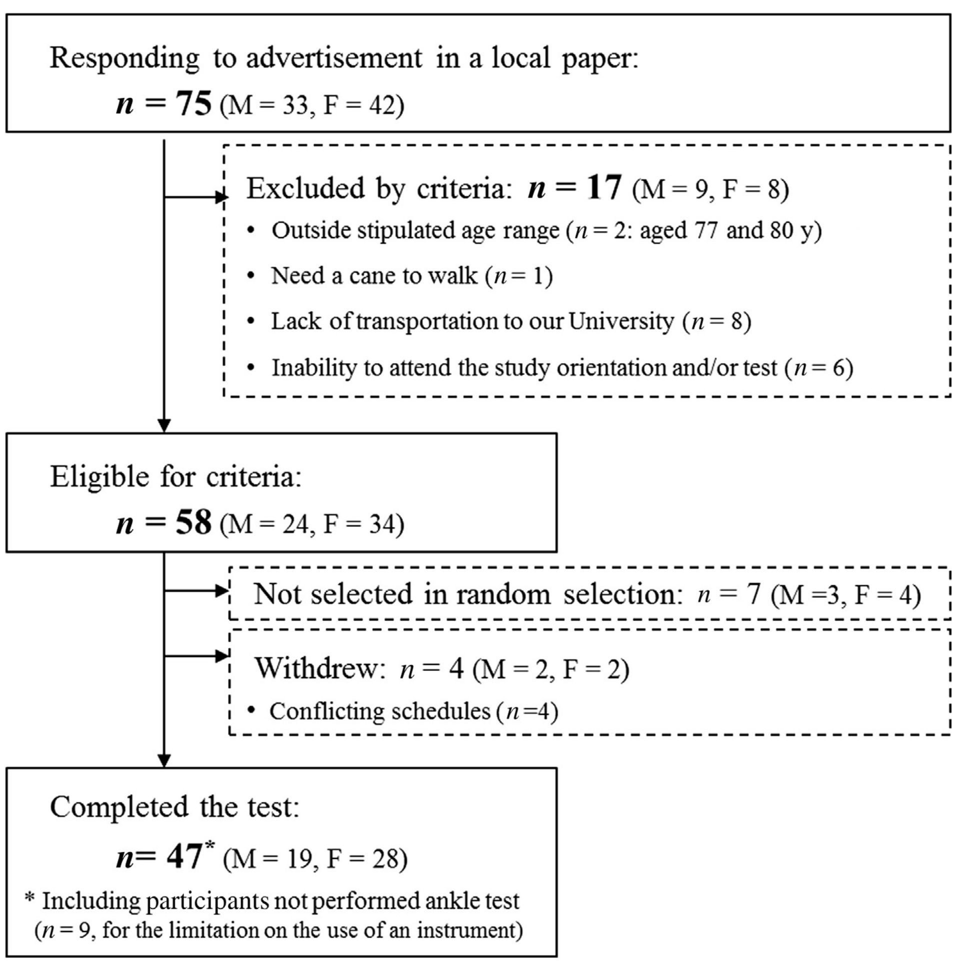

Fig. 1. Flow of participants through the study. F = female; M = male.

isokinetic knee torque and power in random order with a 20-minute interval between tests. We performed the isokinetic ankle test and the five-times STS test 7 days later. To minimize measurement errors, we held the two test sessions at approximately the same time of day. In addition, one investigator performed all ground reaction force measurements for the STS movement and five-times STS test, whereas the other investigator performed all knee and ankle torque and power tests.

2.3. Ground reaction force parameters

After explaining the sitting posture and movement pattern for the STS movement, participants sat in a chair of standard height (40 cm) with legs shoulder-width apart, the trunk stretched vertically in a straight line and their ankles held at 90° on the force plate (TKK5809, Takei Scientific Instruments Co. Ltd., Niigata, Japan). Participants stood up from the chair as fast as possible with arms folded, rested for approximately 2 seconds, and then sat down again. They performed three trials in succession with an interval of 2 seconds. The force plate provided a curve of vertical ground reaction force during the STS movement at 100 Hz (simple moving average: 10).

Based on previous studies[6,7,11,12], we collected five ground reaction force parameters (Fig. 2). The peak reaction force/body weight ($kgf \cdot kg^{-1}$) reflected the maximal downward force pushing the body upwards. Two maximal rate of force development (RFD) parameters were an index of the capacity for rapid muscle force production: the maximal RFD (Δ10 millisecond)/kg (RFD1/w, $kgf/s \cdot kg^{-1}$), which was defined as the steepest gradient of the force-time curve over a given 10-millisecond time frame. RFD9/w ($kgf/s \cdot kg^{-1}$), with a sample duration of 90 milliseconds, helps to assess the muscle exertion over a longer time frame for better reproducibility. There were also two time-related parameters: the time span of the developing force, and the chair-rise time. We evaluated these parameters as the participant's quickness of movement. The highest values of the peak reaction force/body weight, RFD1/w and RFD9/w were selected for analysis. We used the trial with the highest RFD9/w value to determine the values of the time span of the developing force and chair-rise time. The five parameters obtained from the same measurement protocol with the same force plate as the present study have good test reliability (intraclass correlation coefficients of the peak reaction force/body weight, RFD1/w, RFD9/w, the time span of the developing force and chair-rise time were 0.91, 0.51, 0.87, 0.84 and 0.82, respectively)[13].

2.4. Five-times STS test

The five-times STS test was measured according to a previous study[14]. The participants were asked to rise from a chair of standard height (40 cm) five times as fast as possible with their arms folded. The shorter time of the two trials was used for analyses.

2.5. Knee and ankle peak torque and average power

A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) was used for testing peak torque and average power. Peak torque and average power during isokinetic (60°/s) knee extension and flexion as well as ankle plantar flexion and dorsiflexion were measured in the dominant leg. We determined leg dominance by requesting the participant to kick a ball. Calibration was performed before each test session as per the manufacturer's specifications. All isokinetic values were corrected for the effect of gravity.

Participant positioning for the isokinetic knee extension and flexion trials has been described previously[15]. The two trials were performed separately. For each trial, participants performed two submaximal and two maximal contractions before testing, and then three maximal voluntary contractions with the knee joint approximately maintained between 90° and 180°. A minimum 5-minute rest was allowed between the two trials to exclude the effect of fatigue.

For the ankle plantar flexion and dorsiflexion trials, participants were semi-reclined with knees at 15° flexion, and the back of the seat tilted to approximately 80°. The participants were stabilized with two shoulder straps, a waist strap, a thigh strap, and an auxiliary pad fixed under the calf. The foot was attached to a footplate and fixed with two belts. The ankle joint was aligned with the axis of the dynamometer. Isokinetic plantar flexor and dorsiflexor trials were performed separately. For each trial, the participant performed two submaximal and two maximal contractions before testing. For the actual test, the participant performed four maximal voluntary contractions through the full active range of motion of the ankle joint, resting at least 5 minutes between the two trials.

Isokinetic peak torque and average power were calculated using the Biodex System 3 Advantage software (version 3.03; Biodex Medical Systems, Shirley, NY, USA), and the highest value from each trial was recorded. Torque and power data were normalized/kg of body weight (Nm/kg and W/kg, respectively).

2.6. Statistical analyses

We initially calculated descriptive statistics for participant characteristics. We used Student t test for continuous variables and Chi-square test for categorical variables to detect sex differences. We conducted partial correlation analyses according to sex and adjusted for age, to examine the relationships among the ground reaction force parameters in an STS movement, the five-times STS results and lower limb muscle strength and power values. We calculated 95% confidence intervals for all partial correlation coefficients. All analyses were conducted using SPSS Statistics for Windows, Version 17.0 (SPSS Inc., Chicago, IL, USA). A p value <0.05 was considered significant.

3. Results

3.1. Descriptive data of participants

Table 1 contains the descriptive details of participants. The mean age was 69.0 ± 2.9 years. Significant sex differences were found in height, body weight, the peak reaction force per body weight, all knee extension and flexion variables, and ankle dorsiflexion peak torque.

3.2. Relationships among ground reaction force parameters, five-times STS test, and lower limb torque and power

Table 2 shows partial correlations among the ground reaction force parameters in an STS movement, the five-times STS results and knee and ankle torque and power values. In men, RFD9/w correlated significantly with isokinetic knee extension and flexion average power (partial-$r = 0.51$ and partial-$r = 0.54$, respectively; $p < 0.05$). In women, the peak reaction force per body weight and RFD9/w correlated significantly with all four isokinetic knee parameters and ankle plantar flexion average power (partial-$r = 0.39–0.50$; $p < 0.05$). RFD9/w, the time span of the developing force and chair-rise time also correlated significantly with isokinetic ankle dorsiflexion parameters (partial-$r = 0.44–0.59$; $p < 0.05$). No isokinetic parameters, however, were significantly related to any five-times STS measurements in either sex

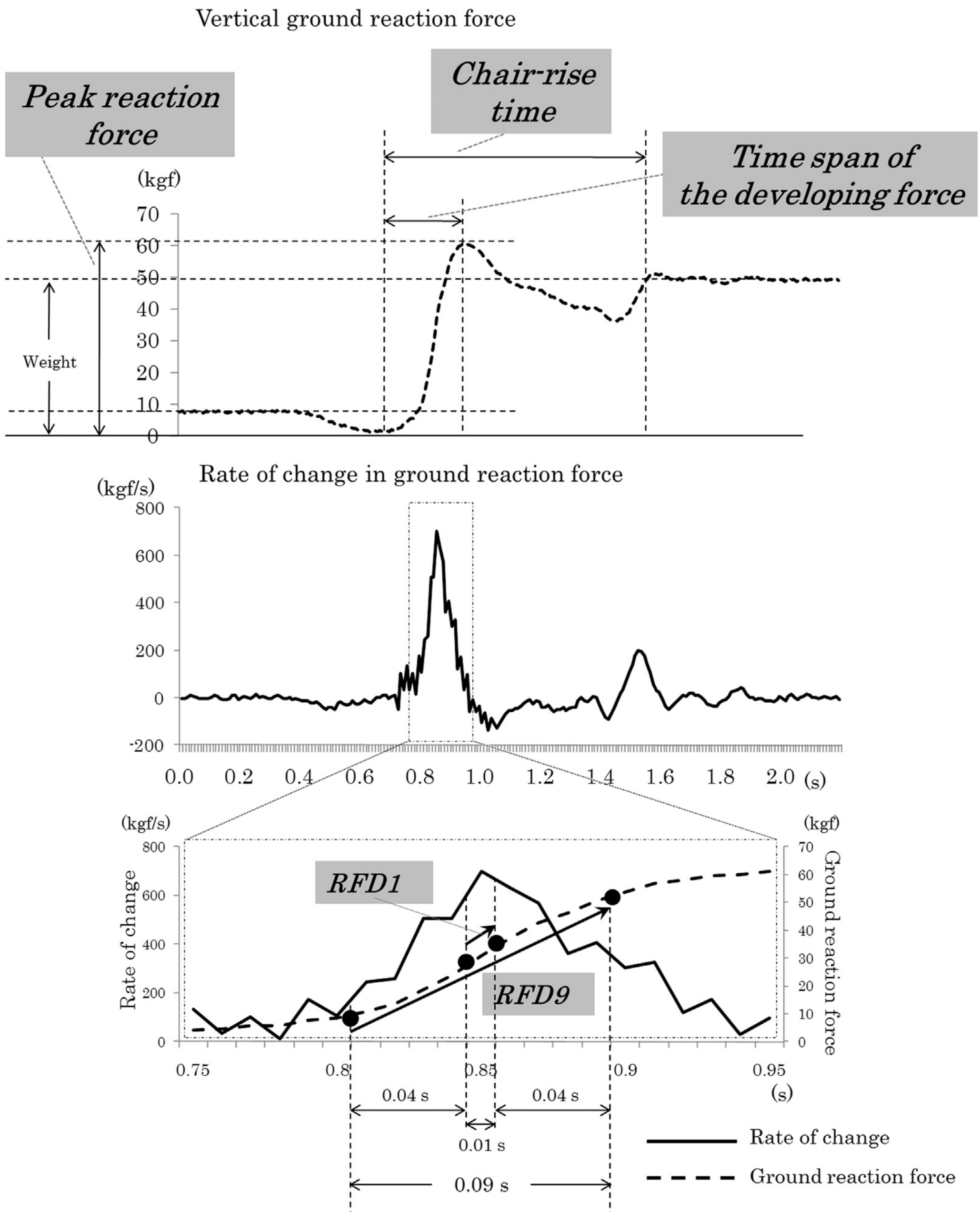

Fig. 2. Ground reaction force parameters. RFD1 = maximal rate of force development (Δ10 ms); RFD9 = maximal rate of force development (Δ90 ms).

(partial-|r| = 0.03–0.31). There was a linear relationship between RFD9/w and isokinetic knee extension average power in both sexes (Fig. 3).

4. Discussion

The present study is the first to investigate associations among vertical ground reaction force parameters in an STS movement and lower limb dynamic strength and power. The ground reaction force parameters (especially RFD9/w) in an STS movement were associated with isokinetic knee and ankle strength and power. However, the five-times STS results had little association with isokinetic strength or power. This suggests that ground reaction force parameters in an STS movement can accurately reflect the isokinetic strength and power in the knees and ankles, which is approximately equal to or better than the strength and power reflected by the five-times STS test. Therefore, this measurement method can be a novel field test for evaluating lower limb muscle strength and power in the clinical setting of preventive nursing care for older adults.

Until recently, the relationship between lower limb muscle strength and the ground reaction force in an STS movement was unclear. Yamada and Demura[7] reported that ground reaction force parameters showed a moderate correlation (|r| = 0.29–0.64) with isometric knee extension muscle strength in older women. In the present study, RFD9/w was related to dynamic knee extension and flexion power in both sexes. Moreover, dynamic ankle plantar flexion and dorsiflexion power were also related to RFD9/w in women. In previous studies[16,17], RFD during isometric knee extension was used to evaluate the ability to develop force rapidly, which

Table 1
Descriptive data of participants.

	All (n = 47)		Men (n = 19)		Women (n = 28)	
	Mean	SD	Mean	SD	Mean	SD
Characteristics						
Age (y)	69.0 ± 2.9		69.6 ± 2.9		68.6 ± 2.9	
Height (cm)	157.6 ± 7.2		164.4 ± 3.8		153.0 ± 4.8*	
Body weight (kg)	57.2 ± 9.3		63.8 ± 7.7		52.7 ± 7.5*	
Body mass index (kg/m^2)	23.0 ± 2.8		23.6 ± 2.6		22.5 ± 2.9	
Systolic blood pressure (mmHg)	139 ± 20		142 ± 16		137 ± 1	
Diastolic blood pressure (mmHg)	81 ± 10		84 ± 9		79 ± 10	
Medication use (piece)	1.4 ± 1.7		1.6 ± 2.3		1.2 ± 1.2	
Lower limb pain†, yes % (n)	12.8 (6)		15.8 (3)		10.7 (3)	
Lower back pain†, yes % (n)	10.6 (5)		10.5 (2)		10.7 (3)	
Ground reaction force parameters						
Peak reaction force/body weight (kgf·kg^{-1})	1.43 ± 0.11		1.49 ± 0.09		1.39 ± 0.10*	
RFD1/w (kgf/s·kg^{-1})	16.82 ± 3.70		17.59 ± 3.48		16.29 ± 3.81	
RFD9/w (kgf/s·kg^{-1})	11.14 ± 1.48		11.56 ± 1.43		10.85 ± 1.47	
Time span of the developing force (ms)	282 ± 68		302 ± 74		269 ± 62	
Chair-rise time (ms)	782 ± 92		793 ± 88		774 ± 96	
Lower-limb strength and power						
Knee extension						
Peak torque (0°/s) (Nm/kg)	2.15 ± 0.45		2.35 ± 0.48		2.01 ± 0.38*	
Peak torque (60°/s) (Nm/kg)	1.55 ± 0.38		1.70 ± 0.32		1.46 ± 0.39*	
Average power (60°/s) (W/kg)	0.85 ± 0.26		0.99 ± 0.25		0.76 ± 0.21*	
Knee flexion						
Peak torque (60°/s) (Nm/kg)	0.81 ± 0.19		0.93 ± 0.16		0.73 ± 0.17*	
Average power (60°/s) (W/kg)	0.56 ± 0.15		0.65 ± 0.14		0.49 ± 0.12*	
Ankle plantar flexion‡						
Peak torque (60°/s) (Nm/kg)	0.88 ± 0.29		0.93 ± 0.29		0.84 ± 0.28	
Average power (60°/s) (W/kg)	0.46 ± 0.16		0.50 ± 0.17		0.44 ± 0.15	
Ankle dorsiflexion‡						
Peak torque (60°/s) (Nm/kg)	0.24 ± 0.06		0.26 ± 0.05		0.22 ± 0.06*	
Average power (60°/s) (W/kg)	0.13 ± 0.04		0.14 ± 0.04		0.12 ± 0.03	
Timed test						
Five-times sit-to-stand (s)	7.37 ± 1.43		7.41 ± 1.21		7.35 ± 1.58	

RFD1 = maximal rate of force development (Δ10 ms); RFD9 = maximal rate of force development (Δ90 ms); SD = standard deviation; w = body weight.
* $p < 0.05$ (presence of sex difference).
† χ^2 test.
‡ $n = 39$ (men: 17, women: 22).

plays an important role in muscle power. Moreover, our results may help in understanding the misinterpreted curve of Fleming et al[12], in which RFD in an STS movement was equated with power. This association is incorrect in terms of physics, because power is defined as the amount of work performed over a period of time or by multiplying the force and velocity. However, we observed that this variable correlated well with lower limb power. Furthermore, McGibbon et al[18] investigated the relationship between ground reaction force in an STS movement and the time to lift-off from the seat, and demonstrated that RFD9/w is probably achieved around the time of lift-off. Therefore, this appearance time of RFD9/w is the transfer phase between Phase I, where the ankle dorsiflexor strength plays an important role, and Phase II, where knee extensor strength plays an important role[10]. Because the center of balance that is transferred from the buttocks to feet and the body weight is lifted upward from sitting to standing, participants who exerted sufficient knee and ankle strength also recorded superior RFD9/w results in our study.

We found a poor correlation between the five-times STS results and lower limb strength and power. Our results are in accordance with those of Netz et al[5], who reported that the multiple-STS test did not predict isokinetic strength of knee extensors, but rather, general endurance in older adults. Furthermore, Lord et al[19] found that performance of the five-times STS test was influenced by multiple physiological and psychological processes, such as proprioception and vitality, and represented a particular transfer skill, rather than a proxy measure of lower limb strength. Thus, ground reaction force parameters may also be affected by these processes; however, measuring RFD in an STS movement may attenuate the impact of factors other than lower limb strength or power because force output can be directly measured with the force platform. Furthermore, the moderate correlation observed between RFD9/w and knee extension/flexion power in this study was greater than the correlations (partial-r, controlled for age = 0.01–0.28) observed in previous studies[19] between STS performance and sensorimotor, balance, or psychological factors. Moreover, most studies, including the present one, included cross-sectional investigations of STS performance and its relationships with muscle strength and power. Therefore, causality based on longitudinal research cannot be determined. However, STS movement is a functionally coordinated movement of multiple joints; thus, measurements of muscle strength and power for individual joints can be considered as important independent variables. In addition, participants in the present study who recorded higher monoarticular muscle strength and power measurements could step on the ground quicker and with greater force during STS movements, and they showed superior ground reaction force parameters.

The ground reaction force parameters in an STS movement were associated with more parameters of lower limb strength and power in women than in men. One reason may be the fixed chair height (40 cm). A lower chair changes the chair rise strategy so that maintaining stability is a priority making the STS movement more difficult[20,21]. In the present study, men were taller than women; thus, the burden on the lower limbs might be greater in men. In a previous study[7] on ground reaction force parameters and knee strength, participants were older women who stood up from a 40-

Table 2
Partial correlation coefficients between ground reaction force parameters, and knee and ankle peak torque and average power.

	n	Peak reaction force/body weight ($kgf \cdot kg^{-1}$)	RFD1/w ($kgf/s \cdot kg^{-1}$)	RFD9/w ($kgf/s \cdot kg^{-1}$)	Time span of the developing force (ms)	Chair-rise time (ms)	Five-times sit-to-stand (s)
		partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)	partial-*r* (95% CI)
Men							
Knee extension							
Peak torque (60°/s) (Nm/kg)	19	0.07 (−0.40, 0.51)	−0.20 (−0.60, 0.28)	0.08 (−0.39, 0.52)	0.14 (−0.34, 0.56)	0.16 (−0.32, 0.57)	0.18 (−0.30, 0.59)
Average power (60°/s) (W/kg)	19	0.26 (−0.22, 0.64)	0.23 (−0.25, 0.62)	0.51 (0.07, 0.78)*	−0.27 (−0.65, 0.21)	−0.25 (−0.63, 0.23)	−0.09 (−0.52, 0.38)
Knee flexion							
Peak torque (60°/s) (Nm/kg)	19	0.17 (−0.31, 0.58)	0.02 (−0.44, 0.47)	0.26 (−0.22, 0.64)	−0.00 (−0.45, 0.45)	0.01 (−0.45, 0.46)	−0.03 (−0.48, 0.43)
Average power (60°/s) (W/kg)	19	0.24 (−0.24, 0.63)	0.28 (−0.20, 0.65)	0.54 (0.11, 0.80)*	−0.38 (−0.71, 0.09)	−0.30 (−0.66, 0.18)	−0.23 (−0.62, 0.25)
Ankle plantar flexion							
Peak torque (60°/s) (Nm/kg)	17	−0.19 (−0.61, 0.32)	−0.28 (−0.67, 0.23)	−0.05 (−0.52, 0.44)	0.10 (−0.40, 0.55)	0.07 (−0.42, 0.53)	0.30 (−0.21, 0.68)
Average power (60°/s) (W/kg)	17	−0.08 (−0.54, 0.42)	−0.12 (−0.57, 0.38)	0.11 (−0.39, 0.56)	−0.11 (−0.56, 0.39)	−0.11 (−0.56, 0.39)	0.10 (−0.40, 0.55)
Ankle dorsiflexion							
Peak torque (60°/s) (Nm/kg)	17	0.25 (−0.26, 0.65)	0.08 (−0.42, 0.54)	0.28 (−0.23, 0.67)	−0.45 (−0.77, 0.04)	−0.25 (−0.65, 0.26)	−0.31 (−0.69, 0.20)
Average power (60°/s) (W/kg)	17	0.43 (−0.06, 0.75)	0.27 (−0.24, 0.66)	0.46 (−0.03, 0.77)	−0.49 (−0.79, 0.00)	−0.37 (−0.72, 0.13)	−0.23 (−0.64, 0.28)
Women							
Knee extension							
Peak torque (60°/s) (Nm/kg)	28	0.43 (0.07, 0.69)*	0.38 (0.01, 0.66)*	0.47 (0.12, 0.72)*	0.05 (−0.33, 0.42)	−0.22 (−0.55, 0.17)	−0.13 (−0.48, 0.26)
Average power (60°/s) (W/kg)	28	0.41 (0.04, 0.68)*	0.34 (−0.04, 0.63)	0.45 (0.09, 0.70)*	0.03 (−0.35, 0.40)	−0.23 (−0.56, 0.16)	−0.17 (−0.51, 0.22)
Knee flexion							
Peak torque (60°/s) (Nm/kg)	28	0.44 (0.08, 0.70)*	0.21 (−0.18, 0.54)	0.39 (0.02, 0.67)*	0.13 (−0.26, 0.48)	−0.14 (−0.49, 0.25)	−0.31 (−0.61, 0.07)
Average power (60°/s) (W/kg)	28	0.39 (0.02, 0.67)*	0.20 (−0.19, 0.53)	0.39 (0.02, 0.67)*	0.03 (−0.35, 0.40)	−0.16 (−0.50, 0.23)	−0.30 (−0.61, 0.08)
Ankle plantar flexion							
Peak torque (60°/s) (Nm/kg)	22	0.38 (−0.05, 0.69)	0.57 (0.20, 0.80)*	0.38 (−0.05, 0.69)	−0.12 (−0.52, 0.32)	−0.37 (−0.68, 0.06)	−0.20 (−0.57, 0.24)
Average power (60°/s) (W/kg)	22	0.48 (0.07, 0.75)*	0.63 (0.28, 0.83)*	0.50 (0.10, 0.76)*	−0.14 (−0.53, 0.30)	−0.46 (−0.74, −0.05)*	−0.22 (−0.59, 0.22)
Ankle dorsiflexion							
Peak torque (60°/s) (Nm/kg)	22	0.29 (−0.15, 0.63)	0.22 (−0.22, 0.59)	0.44 (0.02, 0.73)*	−0.48 (−0.75, −0.07)*	−0.59 (−0.81, −0.22)*	−0.21 (−0.58, 0.23)
Average power (60°/s) (W/kg)	22	0.38 (−0.05, 0.69)	0.24 (−0.20, 0.60)	0.49 (0.09, 0.76)*	−0.51 (−0.77, −0.11)*	−0.57 (−0.80, −0.20)*	−0.14 (−0.53, 0.30)

*$p < 0.05$.
CI = confidence interval; RFD1 = maximal rate of force development (Δ10 ms); RFD9 = maximal rate of force development (Δ90 ms); w = body weight.

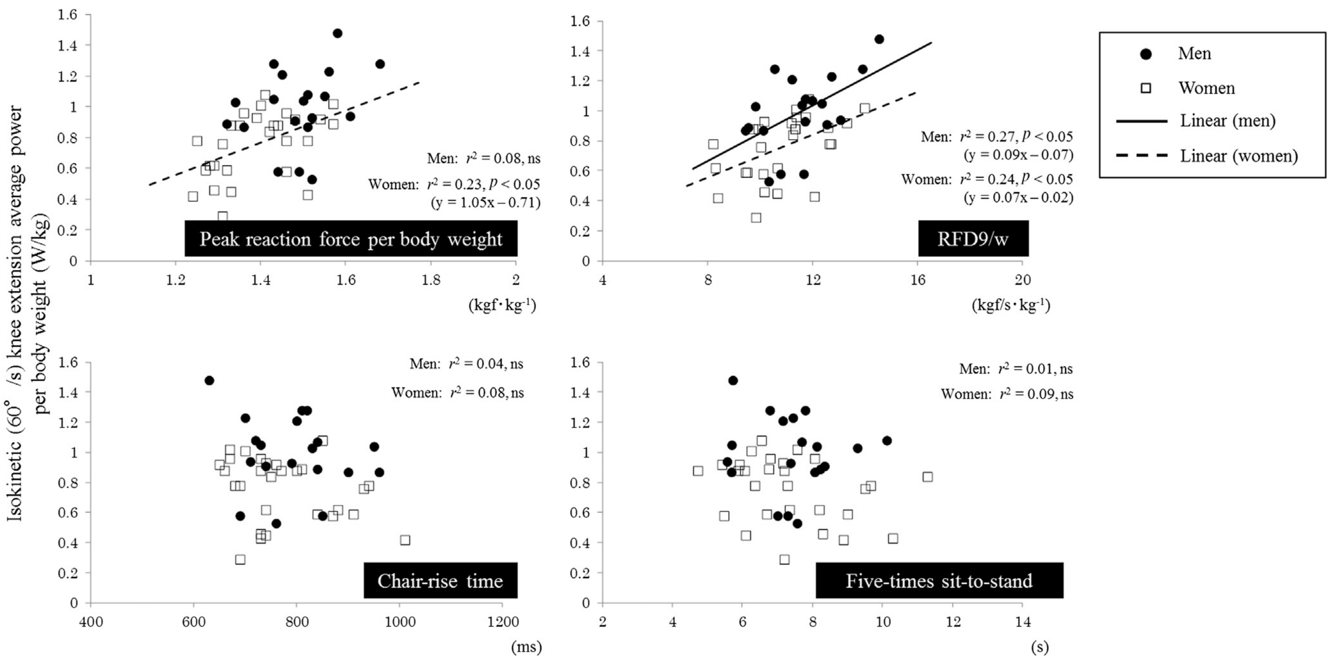

Fig. 3. Univariate regression analyses of peak reaction force/body weight, maximal rate of force development (Δ90 ms)/body weight (RFD9/w), chair-rise time and five-times sit-to-stand results versus isokinetic knee extension average power.

cm high chair. This suggests that a 40-cm high chair may not be appropriate for many older men; they require a taller or adjustable chair. It should be stressed, however, that only RFD9/w correlated significantly with knee extension and flexion power in men.

Unfortunately, this measurement method is not yet as practical as a field test, due to the need for specialized equipment that at present is relatively expensive. However, because several studies, including our current study, have shown this measurement method to be reliable and valid, equipment that is reasonably priced and easy to operate can be developed for general public use. For example, incorporating this measurement system into a body weight scale could lead to its widespread household use. Furthermore, individuals can use this equipment to perform measurements on themselves even in the absence of an experienced tester. The present study provides basic information that can be used to develop this novel equipment for general use.

Our study had some limitations. First, the participants may not represent all older adults because they were candidates for the training program at the university. We targeted relatively healthy older adults to ensure greater safety while performing the strenuous tests. We expect that the associations between the ground reaction force parameters and lower limb strength and power would be stronger for participants with functional limitations or severe pain because of the greater breadth of the distribution. Furthermore, in recent years, this measurement method has been used to assess asymmetry in muscle force loading in patients with knee or hip osteoarthritis[22,23]. If we measure ground reaction force from each leg separately using two force plates, we might gain more insight into participants' physical function. Second, participant physique or the characteristics of the rising strategy were not considered. However, because the ultimate objective of this study was to introduce this measurement method into the clinical setting of preventive nursing-care for older adults, we felt a fixed chair height and less precise control of a participant's STS movement were sufficient. Third, the sample size was too small to detect a statistical difference between the partial-r of ground reaction force parameters and of five-times STS test. Finally, to reduce the burden on participants and because of limitations of equipment used in the present study, we were unable to measure hip flexion/extension strength and power; this also affects the execution of the STS movement.

In conclusion, the vertical ground reaction force parameters in an STS movement can accurately reflect the dynamic strength and power in the lower limbs, which is approximately equal to or better than the strength and power reflected by the five-times STS test. In particular, the maximal RFD (Δ90 millisecond)/body weight variable is well correlated with knee extension and flexion power. Further progress in this measurement method may increase the accuracy and objectivity of measured data for assessment of lower limb muscle strength and power in clinical settings of preventive nursing-care and relieve testing strain on older adults.

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