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Original Article

The relationship between ground reaction force in sit-to-stand movement and lower extremity function in community-dwelling Japanese older adults using long-term care insurance services

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Abstract. [Purpose] The purpose of this study was to investigate which of the four chair-rising methods has low-load and the highest success rate, and whether the GRF parameters in that method are useful for measuring lower extremity function among physically frail Japanese older adults. [Subjects and Methods] Fifty-two individuals participated in this study. The participants voluntarily attempted four types of Sit-to-stand test (one variation without and three variations with the use of their arms). The following parameters were measured: peak reaction force (F/w), two force development rate parameters (RFD1.25/w, RFD8.75/w) and two time-related parameters (T1, T2). Three additional commonly employed clinical tests (One-leg balance with eyes open, Timed up and go and 5-meter walk test) were also conducted. [Results] "Hands on a chair" chair-rising method produced the highest success rate among the four methods. All parameters were highly reliable between testing occasions. T2 showed strongly significant associations with Timed up and go and 5-meter walk test in males. RFD8.75/w showed significant associations with Timed up and go and 5-meter walk test in females. [Conclusion] Ground reaction force parameters in the Sit-to-stand test are a reliable and useful method for assessment of lower extremity function in physically frail Japanese older adults.
Key words: Ground reaction force, Lower extremity function, Long-term care insurance services

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INTRODUCTION

A sit-to-stand movement (hereafter, STS) is one function of the basic activities of daily living that often occurs without conscious awareness; it is also the most fundamental and an indispensable activity for older adults to perform as part of maintaining an independent life[1, 2)]. The ability to perform this basic activity can easily be hampered by disease or aging[3)], and loss of such ability can not only impair physical function and mobility in activities of daily living (ADL), but also result in death[4, 5)]. In one study of community-dwelling frail older people using Japanese long-term care insurance (hereafter, LTCI) services[6)], more than 43% were incapable of performing this important activity. Fortunately, skill in performing STS can be

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improved by adequate training, even in older people[7]. Accordingly, in LTCI services, the measurement and evaluation of individuals' lower extremity function is very important, as are appropriate measures to maintain and improve their physical health and level of independent functioning.

Several studies have reported that the number of repetitions of the STS one can perform within 30 seconds can serve as a measure of lower extremity function in older people, and that the test results are correlated significantly with both age and strength of the lower extremity[8, 9]. Another study had participants sit in chairs with their arms folded over their chests and perform five consecutive repetitions of STS (5-STS) as quickly as possible, with the elapsed time recorded as the test result[10]. This 5-STS score correlates with daily physical activity[11] and with the possibility of future disability[4] and mortality[12]. However, a shortcoming of these tests is that repetition of STS is not an easy task for older people. Among patients with central vestibular dysfunction, 36 of 48 (75.0%)[13] were unable to perform the 5-STS test. Among patients receiving LTCI services, 11 of 58 (19.0%)[14] were unable to perform the test. Therefore, a test that requires fewer repetitions should be developed for those LTCI patients.

Several studies have shown that several GRF parameters during one STS have been shown to correlate with lower limb muscle strength and power[1, 15, 16], physical function[17], mobility limitation and falling[18–20]. GRF parameters have proven useful for the assessment of lower extremity function in healthy older adults. An advantage of this method is that evaluation requires only that the individual be able to stand up from a chair; repetition is not needed. However, to the authors' knowledge, the subjects of such investigations have been healthy older people who can rise from a chair without using their arms the one-repetition STS has not been used at all with older LTCI patients. Therefore, the purpose of this study was to investigate which of the four chair-rising methods has low-load and the highest success rate, and whether the GRF parameters in that method are useful for measuring lower extremity function among physically frail Japanese older adults. Together, these findings should help clarify which methods are valid for measuring ground reaction force parameters as part of LTCI services.

SUBJECTS AND METHODS

Among the 59 subjects initially invited, 6 were excluded for missing data because they discontinued LTCI services before the experiment ended. Ultimately, 24 men and 29 women gave their written consent after they received an explanation of the study. Thirty-one (15 men, 16 women) of the 53 participants took part in the assessment of test–retest reliability. The protocol was approved by the Ethics Committee of the University of Tsukuba (Nov 4, 2014; Ref No., Tai 26-28).

First, the four chair-rising methods were implemented as shown in Fig. 1, with each method for one week. Before performing the STS, participants received thorough explanations about each of the four methods: "arms over chest" chair-rising (AOCCR), "hands on knees" chair-rising (HKCR), "hands on a chair" chair-rising (HCCR), and "hands on a desk" chair rising" (HDCR). The AOCCR method required participants to sit in a chair of standard height (40 cm) with their legs shoulder-width apart, the trunk extended vertically in a straight line, and their ankles held at 90° on the force plate (BM-220, TANITA Co., Ltd. Tokyo, Japan) sampled GRF data during the STS at 80 Hz (simple moving average: 12.5 ms). Participants stood up from the chair as quickly as possible with their arms crossed in front of their chests, rested in a standing position for approximately 2 seconds, and then sat down again. They rested in a sitting position for approximately 2 seconds, and then stood up; this concluded their two trials. The other methods were identical to that of AOCCR, with the following exceptions: in HKCR subjects put their hands on their knees, in HCCR subjects put their hands on the front of a chair seat, and in HDCR, subjects put their hands on a desk 70 cm in height, from a distance of 30 cm from the chair. After thorough explanation and one practice trial, the four chair-rising methods were performed. Secondly, to investigate whether the GRF parameters in that method with low-load and the highest success rate are useful for measuring lower extremity function among physically frail Japanese older adults, participants were asked to perform the physical performance tests in the second week as below. (1) Grip strength. (2) One-leg balance with eyes open. (3) Timed up and go (TUG). (4) 5-meter walk test. In addition, the two tests for the test–retest reliability session were separated by 10 minutes.

Figure 2 shows the five GRF parameters collected for this study with reference to previous studies[16]. Good reliability and validity of these parameters have been reported with healthy older people[16, 17]. The peak reaction force per body weight (F/w, kgf·kg^{-1}) reflects the maximal downward force pushing the body upwards. There were two parameters for maximal rate of force development (RFD). The first was an index of the capacity for rapid muscle force production, the maximal RFD (Δ12.5 ms)/kg (RFD1.25/w, kgf/ s·kg^{-1}), which was defined as the steepest gradient of the force–time curve over a 12.5 ms time frame. The second was RFD8.75/w (kgf/ s·kg^{-1}), with a sample duration of 87.5 ms, which helps to assess muscle exertion over a longer time frame for better reproducibility. There were also two time-related parameters: (T1) the time span of the developing force, and (T2) 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, RFD1.25/w, RFD8.75/w, T1, and T2 were collected for analysis. We used the trial with the highest RFD8.75/w value to determine the values for time span of the developing force and chair-rise time.

First, the χ^2 test was used to investigate the highest achievement rate of the four chair-rising methods and pairwise comparisons with Bonferroni corrections of the p values. We then calculated descriptive statistics for participant characteristics. We used the one-way variable model of intraclass correlation coefficient ($ICC_{1, 2}$) to calculate ICC measured twice by the same person to test the reliability of GRF parameters. We conducted partial correlation analyses according to gender and

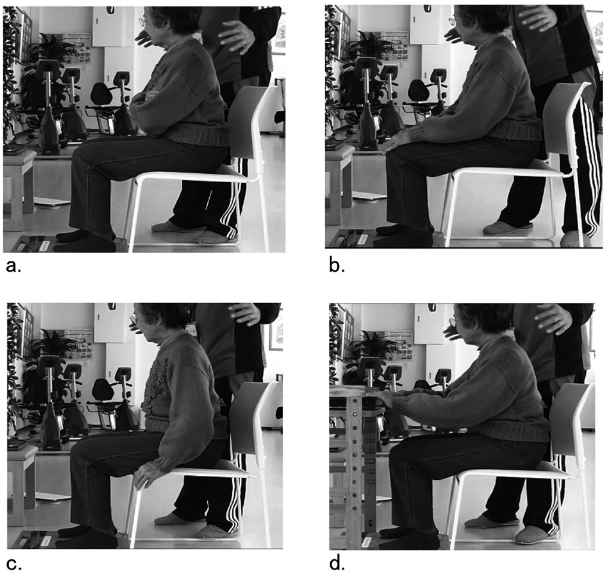

Fig. 1. Starting posture for the four chair-rising methods
a. Starting posture for AOCCR. AOCCR: arms over the chest chair-rising. b. Starting posture for HKCR. HKCR: hands on knees chair-rising. c. Starting posture for HCCR. HCCR: hands on the chair chair-rising. d. Starting posture for HDCR. HDCR: hands on a desk chair-rising.

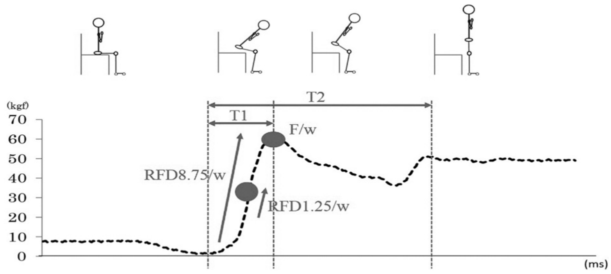

Fig. 2. Ground reaction force parameters
F: peak reaction force; RFD1.25/w: maximal rate of force development (Δ12.5 ms); RFD8.75/w: maximal rate of force development (Δ87.5 ms); T1: time of developing force; T2: chair-rise time; w: body weight

adjusted for age to examine the relationships among the GRF parameters in the STS and physical performance tests. All analyses were conducted using SPSS Statistics for Windows, Version 21.0 and $p<0.05$ was considered significant.

RESULTS

One man among the 53 people using the four types of chair rising methods was unable to stand up from the chair. The achievement rate for HCCR was significantly higher than the chair rising method that AOCCR, HKCR and HDCR ($p<0.01$) (Table 1). 52 of 59 participants' characteristics and physical performance tests' results were shown in Table 2.

ICCs for each parameter were excellent (ICC=0.73–0.89) in men, and (ICC=0.73–0.87) in women, except for F/w and T2. Test-retest reliability strength was classified as excellent (>0.70)[21].

In men, parameters RFD1.25/w, RFD8.75/w, T1, T2, correlated significantly with TUG and 5-meter walk test (partial-$|r|$=0.45–0.81, $p<0.05$). For women, parameters RFD1.25/w, RFD8.75/w, correlated significantly with TUG and 5-meter walk test (partial-$|r|$=0.40–0.48, $p<0.05$). RFD1.25/w, RFD8.75/w, correlated significantly with TUG and 5-meter walk test in both genders (Table 3).

DISCUSSION

The main findings of this study were that the HCCR was the best of the four methods for measuring lower extremity strength in our sample: It was associated with the highest achievement rates, and test-retest reliability was excellent across all GRF parameters in both genders. The significant correlations found between HCCR and physical performance tests support the validity of this test. Our results suggest that the HCCR method can be a reliable and potentially useful tool for the assessment of lower extremity function in physically frail community-dwelling Japanese older adults using LTCI services.

The STS definition that is used most frequently is the one provided by Schenkman that identifies 4 events or phases. Phase I (flexion-momentum phase), Phase II (momentum-transfer phase), Phase III (extension phase), Phase IV (stabilization phase)[22]. As already noted, age-related changes in physical condition have been widely reported to increase the difficulty of STS; the present results suggest that HCCR can be achieved at significantly higher rates than AOCCR, HKCR and HDCR. This result could be explained by a large contribution of hand strength in Phases II and III of HCCR. As has been argued previously, the present results suggest that lower extremity function may play a large role in vertical motion of the center of mass[23]. Yamada already contended in 2010 that, "The contribution of lower extremity function in Phases II and III is considered to be large[1]." Instead, in HKCR, the force of the hands on the knees may increase the burden on the knees in Phases II and III. In HDCR, the height of the desk is 70 cm; therefore, hand strength may contribute little to the STS.

Table 1. The achievement rate of the four of chair-rising method

	n	AOCCR	HKCR	HCCR	HDCR	p value	Post-hoc test
Achievement rate	53	39 (73.6%)	43 (81.1%)	52 (98.1%)	44 (83.0%)	<0.01	AOCCR, HKCR, HDCR < HCCR

AOCCR: arms over the chest chair-rising; HKCR: hands on knees chair-rising method; HCCR: hands on the chair chair-rising method; HDCR: hands on a desk chair-rising method

Table 2. Descriptive data on participants

	All (n=52) Mean ± SD	Men (n=23) Mean ± SD	Women (n=29) Mean ± SD
Characteristics			
Age (years)	83.3 ± 5.3	83.5 ± 5.4	83.2 ± 5.3
Height (cm)	154.5 ± 7.8	159.6 ± 7.4	150.4 ± 5.3
Body weight (kg)	49.2 ± 9.6	51.7 ± 8.0	47.2 ± 10.4
Body mass index (kg/m^2)	20.6 ± 4.0	20.3 ± 2.8	20.9 ± 4.8
Lower back pain, yes n (%)	24 (46.2)	9 (39.1)	15 (51.7)
Knee pain, yes n (%)	16 (30.8)	6 (26.1)	10 (34.5)
Physical performance test			
Grip strength (kg)†	15.6 ± 4.1	17.8 ± 3.9	13.9 ± 3.4
One-leg balance with eyes open (s)‡	8.3 ± 7.5	8.4 ± 8.6	8.2 ± 6.8
Timed Up and Go (s)	14.0 ± 5.8	14.0 ± 6.1	14.0 ± 5.7
Five-m habitual walk (m/s)	0.8 ± 0.3	0.8 ± 0.2	0.9 ± 0.3
Groung reaction force parameters for HCCR			
F/w (kgf · kg^{-1})	1.09 ± 0.09	1.09 ± 0.09	1.08 ± 0.09
RFD1.25/w (kgf/s · kg^{-1})	4.68 ± 2.60	5.45 ± 3.01	4.06 ± 2.07
RFD8.75/w (kgf/s · kg^{-1})	3.64 ± 1.92	4.13 ± 2.23	3.25 ± 1.56
T1 (s)	1.10 ± 0.95	1.11 ± 1.09	1.09 ± 0.84
T2 (s)	1.95 ± 1.01	1.88 ± 1.19	2.01 ± 0.86

SD: standard deviation
†n=51 (men 22, women 29), ‡n=47 (men 20, women 27)
HCCR: hands on the chair chair-rising method; F: peak reaction force; RFD1.25/w: maximal rate of force development (Δ12.5 ms); RFD8.75/w: maximal rate of force development (Δ87.5 ms); T1: time of developing force; T2: chair-rise time; w: body weight

Table 3. Partial correlation coefficients between ground reaction force parameters while performing "hands on the chair chair-rising" (HCCR) method, and physical performance tests adjusted for age

		n	F/w (kgf · kg^{-1}) partial - r	RFD1.25/w (kgf/s · kg^{-1}) partial - r	RFD8.75/w (kgf/s · kg^{-1}) partial - r	T1 (s) partial - r	T2 (s) partial - r
Men							
One-leg balance with eyes open	(s)	21	−0.10	0.10	0.13	−0.33	−0.29
Timed Up and Go	(s)	23	−0.42	−0.53*	−0.60*	0.80*	0.81*
Five-m habitual walk	(s)	23	−0.42	−0.45*	−0.50*	0.67*	0.71*
Women							
One-leg balance with eyes open	(s)	27	0.29	0.04	0.21	−0.06	−0.05
Timed Up and Go	(s)	29	−0.29	−0.40*	−0.44*	0.35	0.33
Five-m habitual walk	(s)	29	−0.26	−0.46*	−0.48*	0.33	0.30

*p<0.05
F: peak reaction force; RFD1.25/w: maximal rate of force development (Δ12.5 ms); RFD8.75/w: maximal rate of force development (Δ87.5 ms); T1: time of developing force; T2: chair-rise time; w: body weight

Reliabilities of GRF parameters during HCCR were also high in men (ICC=0.73–0.89), and in women (ICC=0.73–0.87), except for F/w and T2. Currier proposed that an ICC of ≥0.70 should be considered good[21]. Despite differences between the measuring equipment and the GRF parameters between Yamada's and the present study, the reliability of the GRF parameters for the elderly was (ICC=0.70–0.95)[1] furthermore proposed in men (ICC=0.932) and in women (ICC=0.873)[15]. Moreover, a study in which the measuring equipment and GRF parameters used were the same as those of the present study reported the reliability of the GRF parameters for the healthy elderly was (ICC=0.81–0.91)[17]. The reliabilities in our study for GRF parameters during HCCR in physically frail community-dwelling Japanese older adults using LTCI services were equivalent to or higher than those in the aforementioned reports. Given these considerations, we judged the reliabilities of

GRF parameters to be good.

In the present study, T2 is the 1-time sit-to-stand time, but the T2 of the men showed strongly significant associations with the physical performance tests (TUG and 5-meter walk test) (partial-$|r|$=0.71–0.81, $p<0.05$). In previous studies, it has been estimated that the validity of 5-time STS[24, 25] and 10-time STS[26] is good in the elderly. This may be due to the fact that STS time is an important physical function evaluation index in this age group; in particular, the 1-time STS may be more important than strength in LTCI service assessments in men.

In contrast, RFD1.25/w, RFD8.75/w showed particularly significant associations with the physical performance test (TUG and 5-meter walk test) (partial-$|r|$=0.40–0.60, $p<0.05$), especially both sexes. In previous studies, RFD was used to evaluate the ability to develop rapid isometric knee extension, which plays an important role in the evaluation of muscle strength[27]. Recent studies have suggested the RFD during STS shows strong and significant associations with isokinetic knee extension muscle strength and power in the elderly[15, 16, 28]. Furthermore, Tsuji and colleagues have already argued in 2011 that "The rate of force development (RFD) during STS showed significant to strongly significant associations with performance tests"[17]. In this study, similar correlations were observed for RFD. Given the aforementioned data, in both sexes the validity of the RFD8.75/w GRF parameter in evaluating lower extremity function of physically frail community-dwelling Japanese older adults who are using LTCI services is considered to be large.

The limitations of this study are as follows. First, only cross-sectional data were collected. Future longitudinal studies should establish whether this test method is also valuable in the longer-term and in intervention projects. Second, the study participants all came from the same outpatient a care facility. Third, the number of participants included in the analysis (n=52) was relatively small. Moreover, the present analysis focused mainly on associations with the physical performance tests. The associations of lower extremity strength with mobility limitations and falling must be studied in greater detail in future investigations.

In conclusion, HCCR is the preferable method because it is associated with the highest achievement rates of the four chair-rising methods in physically frail Japanese older adults using LTCI services. The T2 parameter showed strongly significant associations with the TUG and 5-meter walk test (partial-$|r|$=0.71–0.81, $p<0.05$) in men. The RFD8.75/w parameter showed significant associations with the TUG and 5-meter walk test (partial-$|r|$=0.44–0.48, $p<0.05$) in women. These results suggest that the GRF in STS is a reliable and useful method for assessment of lower extremity function in physically frail Japanese older adults using LTCI services. Further in geriatric rehabilitation and physical activity programs, the method discussed in this study may prove helpful for both diagnostic and evaluative purposes.

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