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Can sit-to-stand lower limb muscle power predict fall status?

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ABSTRACT

Sit-to-stand (STS) movements are essential for daily activities. Failure to perform STS movements efficiently and smoothly may lead to falls. In this study, we developed a forceplate to analyze vertical ground reaction force (VGRF), STS duration and generated muscle power to investigate which parameters were fall status predictors. A total of 105 participants were included in this study and were grouped into those (1) aged between 20 and 30 years (Young), (2) aged above 65 years without a history of falling (Non-fallers) and (3) aged above 65 with a history of falling in the past 12 months (Fallers). The results indicated a significantly higher maximal lower limb muscle power (MP) for the Young (9.05 ± 3.66 W/kg), followed by Non-fallers (5.50 ± 2.02 W/kg) and Fallers (3.66 ± 1.45 W/kg) as well as higher modified falls efficacy scale (MFES) scores for the Young (Young: 9.88 ± 0.10; Non-fallers: 6.27 ± 1.40; Fallers: 4.83 ± 0.89) and shorter times for the five times sit-to-stand test (FSTST) for the young (Young: 6.09 ± 2.20 s; Non-fallers: 15.65 ± 3.30 s; Fallers: 19.82 ± 4.46 s). There was a significant difference between the Young group and the Non-fallers in the maximal vertical ground reaction force (VGRF) (138.79 ± 24.20 N/BW in Young, 117.51 ± 8.57 N/BW in old Non-fallers, $p < 0.01$), and there was a significant difference between the Non-fallers and the Fallers in the duration of the STS movement (2.74 ± 0.87 s for the Non-fallers, 4.27 ± 2.56 s for the Fallers, $p < 0.01$). The regression analysis results further indicated that only MP and the STS stabilization phase could differentiate individuals who had past fall events. Therefore, the equipment we developed could potentially be useful in the assessment and monitoring of balance and the risk of falling in older people.

1. Introduction

Falls are a serious problem and can cause significant injuries. People who fall may become fearful of falling, which can further limit their daily activities [1]. Older people are more likely to develop diseases such as stroke and Parkinson's, which also negatively influences their balance [2]. Decreased muscle strength and muscle power impede older people's ability to maintain postural stability in conditions such as stair climbing or lifting objects [3], which may also lead to falls [4,5].

Falls frequently occur during circumstances with increased environmental demand, when there is impaired ability to manage these conditions [6]. To deal with these demands, the velocity of muscle contraction and the force generated by the lower limb muscles must be adequate [7]. Therefore muscle power is related to the occurrence of falls [8]. Leg extension muscle power has been demonstrated to reflect functional performance in older people, and one study has further indicated that muscle power training is more effective for improving physical function than muscle strength training [3]. Because limitations in activities of daily life are considered to be a risk factor for falls [9], decreased muscle power may play a more important role in older people in particular.

The muscle power required for a single-joint movement does not accurately reflect daily physiological activities and cannot be applied to the coordination of multiple-joint movement. Some researchers have chosen more functional compound movements to assess lower limb mobility, such as standing, walking and STS tests [10]. Previous studies have demonstrated that STS ability is

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associated with strength of the knee extensor/flexor muscles, the ankle flexor muscles and with joint motion, balance, proprioception, reaction time and tactile sensation [11,12]. Lindemann used a force plate to evaluate muscle power during STS motion [13]. The results indicated a good correlation with the results of the Nottingham power rig ($r = 0.6$), the gold standard for muscle power measurement. Lindemann's paradigm reduced the impact of differences in body weight, and the testing position resembled the functional movements of daily activities. Fleming et al. (1991) [4] also developed a method to measure power during standing up from a chair by using a force plate. To measure lower limb power safely and conveniently in our study, we developed a set of uniaxial forceplates to collect the mechanical and temporal parameters of the resultant vertical ground reaction force (VGRF) and bilateral lower limb muscle power during the STS movements of young and old participants with or without histories of falling. These data were then compared with clinical balance scales in an attempt to identify fall status predictors.

2. Materials and methods

2.1. Subjects

The participants were grouped into healthy elderly adults aged over 65 (Non-fallers), elderly adults aged over 65 with a history of falling within the last 12 months (Fallers) and healthy young adults aged from 20 to 30 (Young) without a history of falling, according to their self-reported histories. A fall was defined as unintentional coming to a lower level not caused by any external force or influence [14]. This study was approved by the institutional review board of the hospital, and all participants were asked to sign an informed consent form. The exclusion criteria were dizziness or vertigo, degenerative neurological diseases, stroke, lower limb fractures, cardiopulmonary distress and any sensory, visual, auditory or cognitive impairment that would hinder the testing procedures. No participants were taking any drugs known to affect their balance. The details concerning the falls were obtained through an interview.

2.2. Equipment and devices

A forceplate (220 mm × 340 mm) used to measure VGRF was developed in this study. Four compression and tension load cells (TEDEA 615, Vishay Transducers, CA, USA) were installed on the underside of each corner of the plate. The signal acquired by the load cells was first processed with a strain gauge amplifier and followed with analog-to-digital conversion at a 100 Hz sampling rate using a cDAQ-9172 (National Instruments, USA). All data acquisition tasks were programmed by using LabVIEW 8.5 (National Instruments, USA). Matlab software was used to manage and analyze the off-line data.

To ensure the system validity and test–retest reliability, the developed force platform was compared with an AMTI force platform (Watertown, MA, USA), using a free object dropping test. The results indicate that the developed force platform is a valid (±0.01% of full scale error) and reliable (±0.03% of full scale error) measurement system. Ten healthy young adults were tested on the forceplate twice in one week, and the test–retest reliability coefficient was 0.976 using intra-class correlation (ICC 1,3).

2.3. Mechanical and temporal measurements

2.3.1. STS movement test procedures

To reduce the error caused by varied conditions, each subject was asked to perform STS movement with a height adjustable chair without armrests. To ensure subjects started in the same initial position, the seat heights were adjusted so that each subject's hip and knee joints were at 90° and the ankle was at 0° of dorsiflexion [15].

2.3.2. Mechanical parameters

The maximal vertical ground reaction force (MVGRF) is the maximal force generated by subjects during STS tasks and normalized to each subject's body weight. The maximal power (MP) is the maximal product calculated by multiplying the VGRF and the vertical upward velocity of the center of body mass and normalized to each subject's body weight. The peak-to-trough VGRF difference per unit time (PtT/s) is the quantitative difference of the maximal to minimal VGRF divided by the time passed in this phase, which represents the generated VGRF change per unit time during this phase. Curves of acceleration-time and velocity-time were calculated from the recorded ground reaction force (GRF) obtained from the force plate. The time record of the resultant force acting on the subject's center of mass was calculated by subtracting the subject's body weight from the GRF. The velocity-time record was obtained by dividing the resultant force-time record by the subject's body mass to obtain the acceleration-time record and then numerically integrating with respect to time using numerical analysis (trapezoid method). A power-time curve was obtained by multiplying the recorded GRF and velocity. As the velocity-time curve was very sensitive to the initial calculation, we analyzed every single STS movement to ensure accurate calculation.

2.3.3. Temporal parameters

We divided the STS movement into three phases according to Lindemann's study [13]: the preparation phase (PP), the rising phase (RP), and the stabilization phase (SP). During the PP, each subject leaned forward quickly until the flexion of their hip joint reached its maximum. This phase was defined as beginning when there was a change of more than 2.5% in the vertical force transmitted through the feet and lasted until the MVGRF was reached. During the RP, the rising speed of the body's mass is gradually reduced to zero, and the hip and knee joints are gradually extended. The RP begins at the point of MVGRF. The VGRF gradually decreases and then increases in this phase, and the phase ends when the VGRF equals the subject's body weight. In the SP, co-contractions of the calf muscle and anterior tibialis stabilize the body position. The end of this phase is defined as the point at which the VGRF oscillates within 2.5% of the subject's body weight.

2.4. Clinical fall-related assessments

2.4.1. Modified falls efficacy scale (MFES)

The participants were asked to score from 0 to 10 on how confident they were that they could perform 14 daily activities without falling. Higher total scores indicate greater subject confidence [16].

2.4.2. Five times sit-to-stand test (FSTST)

Each subject was instructed to stand up and sit down from a 45-cm height chair with their hands crossed in front of their chests as quickly as possible five times. When the subject stood the fifth time, the examiner stopped timing (to 0.01 s) [17]. The cut-off value for recurrent falling was 15 s [18]. A past study indicated that the FSTST was a predictor of future falling and disability in activities of daily life [19].

2.5. Statistical analysis

The mechanical and temporal parameters derived from the STS tasks and the scores of the two clinical scales were analyzed using