Analysis of the Repeated One-Leg Heel-Rise Test of Ankle Plantar Flexors in Manual Muscle Testing

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Abstract. The purpose of this study was to evaluate the repeated one-leg heel-rise test method of ankle plantar flexors in MMT with kinetic measuring devices and electromyograms (EMG). Seven healthy young males (age, 23 ± 2 y) with no prior history of fractures or surgery involving the lower limbs participated in this study. The ankle and knee motions from flexible electrogoniometers (EGM), ground reaction forces (GRF) and center of pressure (COP) from one force plate and the root-mean-square (RMS) and mean-power-frequency (MPF) from EMG in the medial head of the gastrocnemius and soleus muscles during the repeated one-leg heel-rise test. Kinetic and kinematic data from EGM, GRF and COP were unchanged during the tests. Although the RMS in both muscles and the MPF in the soleus muscles were unchanged during this test, the MPF in the gastrocnemius muscles decreased with the number of iterations (r=–0.79, p<0.001). The MPF of the gastrocnemius muscles in the late phase was significantly lower than in the early and middle phases (respectively, p<0.05, p<0.05). Our results show that this repeated motion method estimates muscle endurance rather than the muscle power.

Key words: Manual muscle testing (MMT), Ankle plantar flexors, Muscle fatigue

INTRODUCTION

Muscle evaluation and training are important for the rehabilitation of patients with movement disorders. Since its introduction by Lovett in the early 1990s, manual muscle testing (MMT) has been widely used by clinicians to assess muscle strength when making training programs and judging rehabilitation effects on patients.

Most of the grading criteria used in MMT are based on the ability to move voluntarily against gravity or the manual resistance added by an examiner, using a 5-point grading scale1–3). However, only the grading scales for the ankle plantar flexors are decided by repetition during the repeated one-leg heel-rise test, using the subject’s body weight as resistance1–3). Many studies have examined the methodologies and judgments while assessing the strength of the ankle plantar flexors with MMT. Svantesson et al.4) suggested that muscle fatigue occurs in the calf muscles during this test. Therefore, a diagnosis of muscle weakness may actually be muscle fatigue caused by repetitive movements.

There is disagreement about the judgment of the grading criteria for “normal” ankle plantar flexors with MMT2–7). A report by Beasley5) proposed five or less heel-rises. On the other hand, Svantesson et al.4) and Lunsford & Perry6) suggested that the grading criteria for “normal” requires 20 or more
heel-rise repetitions in the one-leg standing position. The differences in judgment between these studies may have resulted from the different “successful” tasks as defined by using either electromyography or electrogoniometers. Also, if muscle weakness occurs in ankle plantar flexors, then the kinetic parameters (e.g., center of pressure, ground reaction forces, etc.) of the motor performance will change during the repeated one-leg heel-rise movement. Previous studies\(^4-6\) have not examined this motor task using these measurements simultaneously however. The purpose of this study was to clarify changes in motor performance by carrying out kinematic and kinetic analyses, and to simultaneously investigate the activities of the gastrocnemius and soleus muscles during repeated one-leg heel-rise tests using electromyogram analysis.

METHODS

Subjects

This study recruited 7 healthy males (mean age, 22.6 ± 1.8 years; mean height, 170.3 ± 2.6 cm; mean weight, 60.9 ± 7.9 kg). Informed consent was obtained from each subject according to protocols approved by the Ethical Committee of the College of Medical Technology of Hokkaido University. All subjects were free of any lower limb pain for at least one year prior to the study. Exclusion criteria for all subjects included any previous history of fractures or surgery involving the lower limbs; diseases that could affect motion (e.g., rheumatoid arthritis, spondylolisthesis, etc); or current symptoms of lower limb pain.

Measurements

Two flexible electrogoniometers (EGM) (Biometrics, Cwmfelinfach, Gwent, UK) were used to monitor both ankle and knee joint movements during the one-leg heel-rise test (Fig. 1). One sensor was attached to the outside of the upper and lower thigh for knee motion, while another sensor was attached over the lateral aspects of the lower thigh and the fifth metatarsal bone for ankle motion, as recommended by Biometrics\(^8\). Each sensor was firmly fixed to the skin with double-sided medical tape and covered by single-sided tape to minimize movements between the sensors and the underlying skin. Both Dolan et al.\(^9\) and Thoumie et al.\(^10\) reported this method as having high validity and reliability. The EGM calibration was made in the upright standing position so as to give a zero reading.

Surface electromyogram (EMG) activities were recorded from the medial head of the gastrocnemius and soleus muscles (Fig. 1). After shaving and scrubbing the skin with alcohol, bipolar surface disk electrodes (Ag/AgCl, Blue sensor P-00-S, diameter = 3.3 mm, Ambu, Denmark) were fixed with adhesive tape to each muscle at an inter-electrode distance of approximately 30 mm. The EMG electrodes were placed above the medial heads of the gastrocnemius and soleus muscles according to Basmajian and Blumenstein\(^11\). The ground (reference) electrode was attached to the head of the fibula on the left side. EMG signals were preamplified (× 500) and band-pass filtered between 10 and 500 Hz. The EGM and EMG data were sampled at a frequency of 1 kHz. The EGM and EMG equipment consisted of a Multi-Telemeter system WEB5000 (Nihon Kohden, Tokyo, Japan).

Kinetic data were collected from one force plate (Kistler Instruments AG, Winterthur, Switzerland, 600 × 400 × 35 mm) that assessed anterior-posterior (Fx), medial-lateral (Fy) and vertical (Fz) ground reaction forces (GRF) and the center of pressure (COP). All signals were sent to a PowerLab system (PowerLab /16sp, ADInstruments, Castle Hill, Australia) connected to a Windows PC. PowerLab was equipped with an analog-digital converter (ACD, 16-bit) used to digitize all signals. PowerLab collected data at a frequency of 1 kHz and high-cut filtered raw data at 30 Hz. All digital signals were then transferred to a PC and stored on disc for further analyses. All data were analyzed using Chart software v5.4.2 for PowerLab systems.
The left foot was measured because it was the dominant foot in all subjects. MMT for ankle plantar flexors was performed according to the procedure of Hislop\(^1\). Briefly, each subject stood barefoot in the center of the force plate with an extended knee. Then, the subject put his fingers on the examination table to maintain his balance. The subject was then instructed “to raise his heel as completely as possible 20 times, without losing his balance.” The subject was directed to gaze at the wall directly in front of him and to use a comfortable and constant heel raising velocity.

Ankle and knee joint movements were recorded over all trials. The subject’s body weight provided the applied resistance during the one-leg heel-rise test. To examine the effects of subjects’ body weight on the range of ankle motion during a heel rise in the one-leg position, the maximum ankle plantar flexion (\(\text{PF}_{\theta_{\text{max}}\text{max}}\)) during the first trial was compared with the passive range of motion for the ankle plantar flexion (pROM) measured in the supine position. \(\text{PF}_{\theta_{\text{max}}\text{max}}\) and the maximum knee flexion angle (\(\text{KF}_{\theta_{\text{max}}\text{max}}\)) from an initial position were measured for each trial.

All EMG signals were full-wave rectified and the average amplitude of the rectified signal was calculated using the root-mean-square (RMS) method in each trial. Each trial was modified by a Cosine-Bell window and the fast Fourier transform method was used to obtain the mean-power-frequency (MPF). The peak GRF value in all directions was measured for each trial. All GRF data were normalized for the resting standing position. The maximum movement distance of COP was computed in the anterior–posterior (COPx) and medial-lateral (COPy) directions. COPx and COPy were calculated as a percentage of the foot length and foot width, respectively.

Mean values and standard deviations (SD) are given in the description of the subjects. The mean values and standard errors of the mean (SEM) are given and calculated using conventional methods. Student’s t-test was used to test for differences between pROM and \(\text{PF}_{\theta_{\text{max}}\text{max}}\) during the first trial. One-way repeated measures analysis of variance (one-factor ANOVA) was used for \(\text{PF}_{\theta_{\text{max}}\text{max}}\), \(\text{KF}_{\theta_{\text{max}}\text{max}}\), GRF and COP between each trial to examine performance changes.

Spearman’s Rank correlation coefficient was calculated for EMG data between each trial to examine muscle fatigue\(^4\). Also, EMG data were separated into three phases (Early: 2–7, Middle: 8–13, Late: 14–19) except in the first and last trials, and one-way repeated measures analysis of variance (one-factor ANOVA) was used for each phase. Furthermore, for those values showing a significant difference in ANOVA, Fisher’s PLSD was used to test the significance level. Statview 5.0 software (SAS institutes Inc, Berkley, CA) was used for statistical analysis. The level of significance was set at 0.05.

RESULTS

All subjects satisfactorily performed the twenty heel-rise test with a constant rhythm. Figure 2 shows the raw data of ROM of the ankle and knee joints, EMG of the medial head of the gastrocnemius muscle and soleus muscles and Fz GRF. \(\text{PF}_{\theta_{\text{max}}\text{max}}\) during first trial was lower than pROM,
37.9 ± 1.9, 47.9 ± 1.0 degree, respectively (p<0.01). All subjects were unable to raise their heels to the full range of motion, and thus failed to satisfy the condition for movement range “from 0 degrees up to 45 degrees” indicated by the 7th edition of MMT\(^1\).

There were no significant differences between PF \(\theta_{\text{max}}\) \((F(17,108)=0.508)\) or PF velocity \((F(17,108)=0.355)\) and the number of iterations, and KF \(\theta_{\text{max}}\) was always constant \((F(17,108)=0.119)\). There was no significant difference between trials in both maximum COPx \((F(17,108)=0.312)\) and COPy \((F(17,108)=0.569)\) displacement. The peak Fz GRF was unchanged during the heel-rise movement \((F(17,108)=0.104)\). From these kinematic and kinetic variances, similar motor performances were accomplished over 20 one-leg heel-rise tests.

RMS of the medial head of the gastrocnemius and soleus muscles showed no change during heel-rise movement (Fig. 3a). There was a trend towards decreased MPF of the medial head of the gastrocnemius muscle with increasing number of heel-rises \((R=-0.79, P<0.001, \text{Fig. } 3b)\). The late phase differed from the early \((P<0.01)\) and middle phases \((P<0.01, \text{Table } 1)\). On the other hand, there was no change in the MPF of the soleus muscle during heel-rise movement.

**DISCUSSION**

The present study showed no changes in motor performance during the repeated one-leg heel-rise test in healthy young males. There was no change in RMS and MPF of the EMG in the gastrocnemius muscle of ankle plantar flexors decreased with increasing number of repetitions. There were no changes in either the RMS or MPF of the EMG of the soleus muscle during this test.

Our study shows that the changes in muscle activities are different between the gastrocnemius and the soleus muscle in the ankle plantar flexors. The change in the MPF of the EMG has been used to evaluate the muscle fatigue\(^{12, 13}\). The decrease in MPF is mainly a result of the decrease in action potential conduction velocity\(^{14, 15}\). This decrease in action potential conduction velocity has been found to be related to the lactate concentration in the muscle\(^{16}\). Gerdel et al.\(^{17}\) found correlations between MPF and the single amplitude of the EMG, and suggest that a decrease in MPF along with an
increase or no change in the single amplitude of the EMG is considered to be a practical measurement of muscle fatigue. According to the definition by Lindström et al.\textsuperscript{13)}, no change in RMS and a decrease in MPF indicates the development of muscle fatigue. Therefore, our study suggests fatigue in the medial head of the gastrocnemius, but not in the soleus muscle during repeated one-leg heel-rise test in healthy young males.

The EMG data of the soleus muscle did not change during this motor task. The soleus is located in a deeper position than the gastrocnemius, and it is generally accepted that the gastrocnemius is composed of a mix of fast- and slow-twitch muscle fibers while the soleus is primarily composed mostly of slow-twitch muscle fibers\textsuperscript{18–20). The difference in muscle fatigue between the two muscles may be related to the characteristics of the muscle fiber—the soleus being dominated by type I fibers\textsuperscript{21). Svantesson et al.\textsuperscript{4, 22, 23} and Österberg et al.\textsuperscript{13) reported that muscle fatigue appeared in both the gastrocnemius and the soleus during a standing heel-rise test. We instructed subjects to accomplish the one-leg heel-rise 20 times, whereas Svantesson et al.\textsuperscript{4, 22, 23} and Österberg et al.\textsuperscript{13} instructed subjects to perform the task until no further heel-rises could be performed due to exhaustion. Therefore, muscle fatigue will occur in the medial head of gastrocnemius first and occur in the soleus muscle later.

There is disagreement about the “normal” criterion between studies. Kendal et al.\textsuperscript{7), Beasley\textsuperscript{5) and Daniels et al.\textsuperscript{3) proposed five or less heel-rises. On the other hand, Hislop et al.\textsuperscript{1, 2) Lunsford & Perry\textsuperscript{9) and Svantesson et al.\textsuperscript{4) suggested 20 or more heel-rises. The procedure and definition of the repeated one-leg heel-rise movement differ between these experiments. For keeping balance during this test, subjects were allowed to touch the examine\textsuperscript{6, 24), the wall\textsuperscript{4, 13) or the table\textsuperscript{1, 2) with the finger of one hand\textsuperscript{1–3, 6, 24) or both hands\textsuperscript{4, 13, 22, 23). Also, subjects were instructed to perform the plantar flexion ROM at complete or more than 50% of the starting ROM\textsuperscript{6, 24). Subjects in our study were permitted to touch the table with two fingers of one hand and instructed to perform the ankle plantar flexion ROM at complete starting ROM. Our study showed that subject’s weight influenced PF θmax during the first trial. All kinetic data, however, was unchanged during this study and healthy young males could accomplish 20 heel-rises. Thus, although we support the essential qualification of “normal” is 20 times or more in healthy young males, the criteria repetition of “normal” should consider the subject’s weight, sex and age\textsuperscript{24).}

Muscle strength generally includes the functions of power and endurance\textsuperscript{25). Most MMT evaluate muscle power, but the ankle plantar flexion in MMT does not. Finally, our EMG results show muscle fatigue in the ankle plantar flexors during the repeated one-leg heel-rise test, and suggest that this test estimates muscle endurance rather than muscle power. Therefore, to estimate muscle power, the development of new method is required. Finally, although the motor performance of the 20 repeated one-leg heel-rise movement does not change if MMT is used to assess the muscle power of the ankle plantar flexors in healthy young males, muscle fatigue may potentially occur in the ankle plantar flexors. Since repetitive movements examine muscle endurance rather than power, an improvement in MMT will be required to strictly estimate the muscle power of the ankle plantar flexors in the future.

REFERENCES