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ORIGINAL ARTICLE

Reliability and Validity of the Heel Rise Test Using the Mobile Application

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ABSTRACT

Background. The heel-rise test is a measurement method that can evaluate the muscle endurance and muscle fatigue of the plantar flexor. On the other hand, there is a limit to quantifying the criteria because the evaluation method and criteria differ according to the measurement conditions. **Objectives.** The purpose of this study is to compare the validity and reliability of the smartphone-based measurement application compared to the standardized surface electromyography (sEMG) for measuring muscle fatigue during the heel-rise test. **Methods.** Fifty-seven adults in their 20s participated in the heel-rise test twice a week apart. The concurrent validity for muscle fatigue during the heel-rise test was measured using surface sEMG and 'Calf raise' application, and analyzed through correlation analysis. The intra-rater reliability and inter-rater reliability of the 'Calf raise' application were analyzed using ICC. **Results.** The Pearson correlation coefficient between the 'Calf raise' application and sEMG showed a statistically significant correlation of r=0.509 for both loss (%) and slope value ($p<0.01$). The 'Calf raise' application showed high intra-rater reliability for loss (%) and slope value with ICC (2,1) = 0.986 and 0.987 respectively. It also showed high inter-rater reliability for loss (%) and slope value with ICC (2,1) =0.946 and 0.926. **Conclusion.** The smartphone-based 'Calf rise' application can be usefully used in clinical practice as an evaluation tool capable of not only quantitative evaluation of counting the number of heel-rise tests but also qualitative evaluation of muscle fatigue.

KEYWORDS: ***Electromyography, Heel-rise test, Muscle fatigue, Physical Examination, Equipment, and Supplies.***

INTRODUCTION

The gastrocnemius and soleus cause plantar flexion and play a role in maintaining balance and walking, which is essential for daily life (1-3). They also perform propulsion during toe-off in walking, and the muscle performance produced by the plantar flexor determines the speed and power of gait (4). The biomechanical properties of the plantar flexor have mechanical advantages to produce explosive power against gravity (5, 6).

Among the tests to evaluate muscle performance and muscle fatigue of the plantar flexor, the heel-rise test is used mainly as a quantitative method (4). The heel-rise test is completed repeatedly by performing concentric-eccentric actions of the plantar flexor in a unipedal stance and can be quantified by the total number of heel raises performed (4). The heel-rise test is used widely in various clinical environments, such as confirming the intervention effect of Achilles tendon rupture patients, evaluating the risk of cardiovascular disease, and checking the presence or absence of

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musculoskeletal diseases of the lower extremities (7-11).

The outcome measure used for the heel-rise test is the number of heel raises, but various outcome measurements, such as work, ankle joint range, and torque, can also be used (4, 12, 13). In the case of the heel-rise test, the evaluation method and criteria appear differently depending on the conditions (11, 14). Therefore, it is difficult to quantify the criteria for the heel-rise test (4). Various devices, such as a force plate, linear encoders, motion capture, and inclination sensor, have been used to improve these limitations (15). Among them, sEMG is an effective device for observing changes in muscle fatigue during heel-rise tests (16). But such a device has low accessibility, including complex use, difficult to carry around, and high price ranges.

The smartphone is equipped with sensors such as high-resolution image sensors, global positioning systems (GPS), accelerometers, gyroscopes, and microphones. These sensors can be used as a system that can check various health conditions (17). The smartphone-based applications do not need the manufacture or purchase of additional devices, and their use is widespread, so they have good accessibility (18). In addition, they can be used to measure or evaluate physical functions using such equipment (19).

Several smartphone applications for the heel-rise test have been developed and registered, but insufficient studies are comparing the reliability and validity with standardized instruments. Therefore, this study aimed to compare the correlation and reliability of the heel-rise test using a smartphone-based application with that using an sEMG, which quantifies muscle function.

MATERIALS AND METHODS

Participants. One hundred healthy adults in their 20s who were enrolled in D University were recruited through the recruitment promotion of research participants. Sixty-one of them were selected according to the inclusion and exclusion criteria. The inclusion criteria were those who could repeatedly perform the heel-rise in single-leg standing at least 15 times and those who could understand the purpose of the study and participate voluntarily. The exclusion criteria were (1) those who had an experience with orthopedic surgery or were diagnosed in the ankle, (2) those who had limitations in the range of motion or reduced planar flexor muscle strength, and (3) those who had the last height of the heel of the heel-rise test higher than on the first one. The purpose and process of the study were explained to all participants, and they all signed a written consent form to participate.

Procedures. This study is a cross-sectional study. The sample size was calculated using G power software (ver. 3.192, University of Kiel, Germany). Based on a previous study result that the size of the main effect was (f2): 0.20, the significance level was set to (α) = 0.05, and the power set to (1-β) = 0.8, thereby requiring at least 52 participants (20). In this study, a 10% dropout rate was considered. Therefore, the necessary minimum number of participants was set to 57. Sixty-one people were recruited, and the data from 57 people were collected. Two were excluded for health reasons, and two failed to meet the minimum requirement of the heel-rise count of the heel-rise test.

Before the heel-rise test, the participants performed a comfortable walk for 5 minutes to warm up. The method of the heel-rise test for this study was based on the research by Hebert-Losier et al. (11). In the starting position, the participant's posture was set on an incline to make the ankle approximately 10° dorsiflexion, and the knees and trunk were kept straight. When the test started, the participants repeated raising and lowering their heels at an angular speed of 60°/sec according to the beat of the metronome while maintaining a standing position on one leg. The participants were permitted to apply for fingertip support at shoulder height on a wall in front of them to help balance. The heel-rise test was performed until the participants could maintain the heel-rise cycle with the lower limb and trunk straightened and with fingertip support.

To measure changes in muscle fatigue during a heel-rise test, we use sEMG and application (‘Calf Raise’, developed by Kim Hébert Losier, 2020). To compare changes in muscle fatigue in two sets of data with different units of measurement, we defined 'loss (%)' and 'slope' values. 'Loss (%)' means the rate of change in relative muscle fatigue by the heel-rise test, and 'slope' means the slope of the change in muscle fatigue. A correlation analysis was conducted to compare the concurrent validity between the two measures. To confirm the clinical usefulness of the application, we analyzed the inter-rater reliability and inter-rater reliability of the ‘Calf raise’ (Figure 1).

Surface electromyography. sEMG (Myosystem 1400A, Noraxon Inc., U.S.A.) was

used to measure the change in muscle fatigue during the heel-rise test. The participant's skin was prepared by swiping the skin softly with very fine sandpaper and wiping it with alcohol before attaching the electrodes. The electrodes were attached to medial gastrocnemius (GCM), lateral GCM, and ground electrodes. The medial GCM electrodes were placed on the medial part of the belly on the calf under the popliteal fossa. The lateral GCM electrodes were placed on the lateral part of the belly of the calf under the popliteal fossa. The ground electrodes were placed at the lateral malleolus (21). EMG signal analysis software (Myoresearch XP Master Edition, Noraxon Inc., U.S.A.) was used to analyze the participants' EMG signal data. The EMG signals were collected at a sampling rate of 1000 Hz. The signal was processed by 20–500 Hz bandpass filtering, full wave filtering, and the root mean square with a window of 125ms. Fast Fourier transform analysis was used to calculate the median frequency value for each heel-rise during the heel-rise test. The change in the muscle fatigue value is expressed as a percentage (%) of the average of the median frequency value for the last three heel rises compared to the average of the median frequency value for the initial three heel rises. The slope of the median frequency change is expressed as the regression coefficient (slope) of the regression equation simple linear regression analysis for the median frequency for each heel rise.

Smartphone application. An iPhone 12 (A2403, Apple Inc., U.S.A.) was used to measure the change in ankle movement during the heel-rise test. The camera was set to a distance of 1m from the participant and 50cm above the floor, with the participant's midsagittal plane passing the center of the image. The video was recorded at 60Hz, and a 40mm diameter red marker was attached to the midpoint of both malleolus to capture the heel-rise movement (Figure 2).

The 'Calf raise'(developed by Kim Hebert Losier, 2020) application was used to analyze the change in ankle movement in the video. The motion capture used to Calf Raise is designed based on algorithms that have proven reliability and validity (22, 23). That application included computer vision algorithms applying the Apple Vision framework (Apple Inc., U.S.A.) designed to detect motion trajectory automatically. The calf raise application indicated a decrease in the height of the last heel rise compared to the height of the first heel rise expressed as a loss (%) during the heel-rise test. The slope is expressed as the regression coefficient (slope) of the regression equation calculated from simple linear regression analysis for the peak height value for each heel rise.

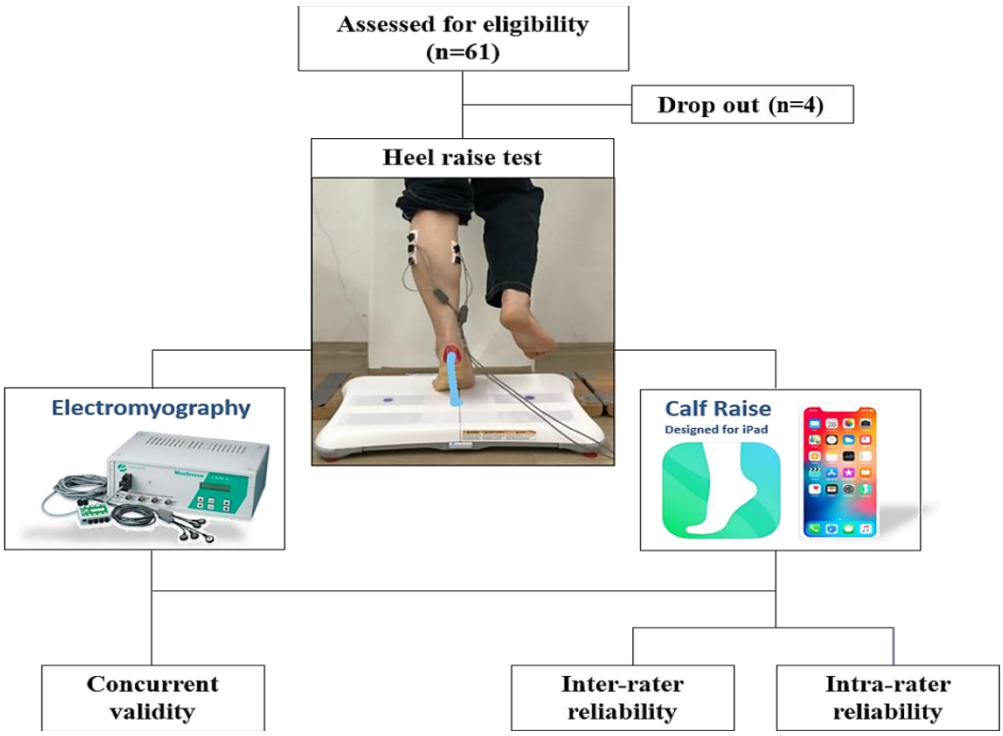

Figure 1. Flow chart of this study

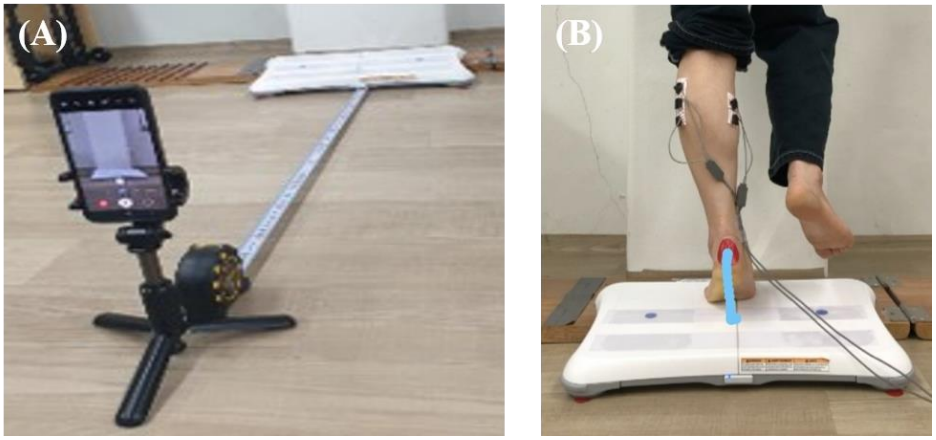

Figure 2. Measuring ankle movement,
(A): set the position of the camera, (B): capture heel movement

Statistical analysis. The result value between each measuring device is reported as the mean and standard deviation (SD). The Shapiro–Wilk test was used for the participant's normality test. The Pearson correlation coefficient was used for correlation analysis for the Calf raise application, sEMG. The measured values of the devices were compared by calculating the 95% limit of agreements (95% LOA) (24). The measured values between the devices are displayed in a diagram form using the Bland-Altman graph.

ICC (2, 1) was used for the test-retest reliability analysis. If the ICC value was less than 0.750, it was said to be medium or low (moderate); it was good from 0.750 to 0.900 and excellent for more than 0.900 (25). CVME data calculated the coefficient of variation using SD calculated from the data of each device and converted it into a percentage (ME=SD/√2, CVME=2ME/(X1+X2) ×100%). In addition, the minimum detectable change (MDC) was determined by calculating 1.96×SEM×√2 to confirm that the participant's measurement data appeared at a confidence level of 95%. The calculated MDC was then converted to a percentage of the mean before MDC 95% was calculated (26). The data were analyzed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Co., Armonk, NY, USA), and Medicalc ver. 19.3.1 (Medicalc software, Ostend, Belgium). All statistical significance levels (α) were set to 0.05.

RESULTS

Table 1 lists the general characteristics of the participants. In the case of the correlation coefficient between the two devices, the Pearson correlation coefficient 'r' value of the loss value was 0.509 ($p<0.01$). The 95% LOA was -13.01 to 22.90, which showed that the results were mostly symmetrical (Table 2). For the slope value, the Pearson correlation coefficient 'r' value of the loss value was 0.509 ($p<0.01$). The 95% LOA was -0.32 to 0.69, which showed that the results were mostly symmetrical (Figure 3).

Table 3 lists the intra-rater reliability of the test–retest measurement in the calf raise application data. For the loss and slope values, the ICC was 0.986 (0.980–0.990) and 0.987 (0.981–0.991), respectively, which showed a high concordance rate. For each 95% LOA, the loss value was –4.48 to 4.55, and the slope was –0.12 to 0.12, which showed that the results were mostly symmetrical. The MDC% of each value was 0.75% and 0.01%, indicating that the absolute reliability between the test and retest was strong (Figures 4, 5).

Table 1. General characteristics of subjects (Mean ± SD)

Sex (male/female)	24/33
Age (years)	22.91±2.13
Height (cm)	167.24±9.05
Weight (kg)	63.58±13.37
Foot size (mm)	251.25±17.93

Table 2. Correlation between EMG and 'Calf raise' application (n = 57)

	EMG	Smartphone application	Pearson correlation coefficient 'r'	95% LOA
Loss (%)	-16.57±8.49[a]	-21.51±9.79	0.509**	-13.01~22.90
Slope	-0.41±0.23	-0.59±0.26	0.509**	-0.32~0.69

[a]: mean ± standard deviation
**: Correlation is significant at the 0.01 level (2-tailed)

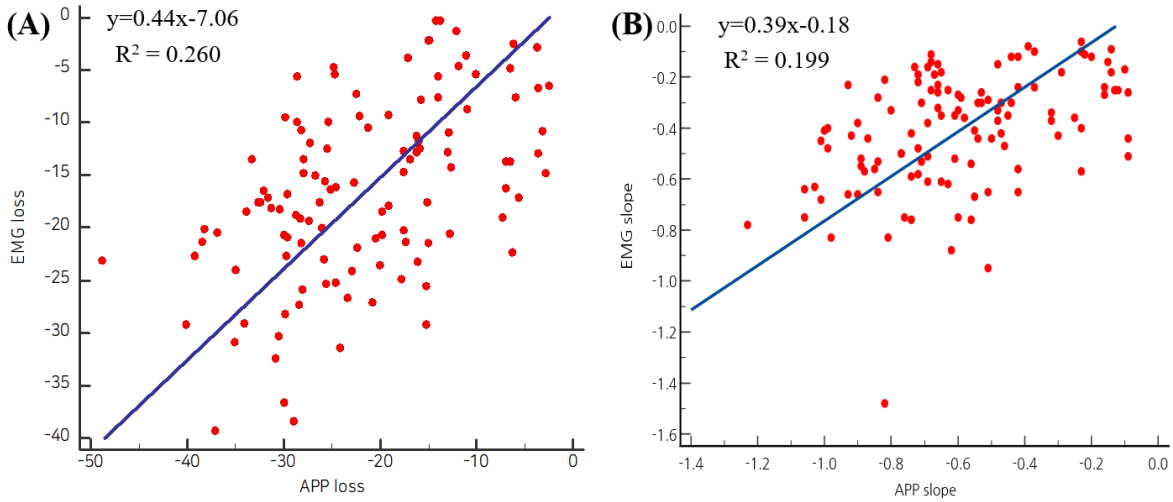

Figure 3. Relationship between EMG and Calf raise application for calf raise test variables in the subject (A: Correlation EMG and APP; B: Slope Altman test of EMG and APP)

Table 3. Intra-rater reliability using the 'Calf raise' application (n = 57)

	Session 1	Session 2	ICC (95%CI)	95% LOA	CV_{ME}%	MDC%
Loss (%)	-21.51±9.79[a]	-21.54±9.81	0.986 (0.980~0.990)	-4.48~4.55	-7.53	0.75
Slope	-0.59±0.26	-0.96±0.26	0.987 (0.981~0.991)	-0.12~0.12	-0.07	0.01

[a]: mean ± standard deviation
ICC = intra correlation coefficient; *95% LOA* = 95% limits of agreements;
CVME% = coefficients of variation of method error %; *MDC%* = minimum detectable change %

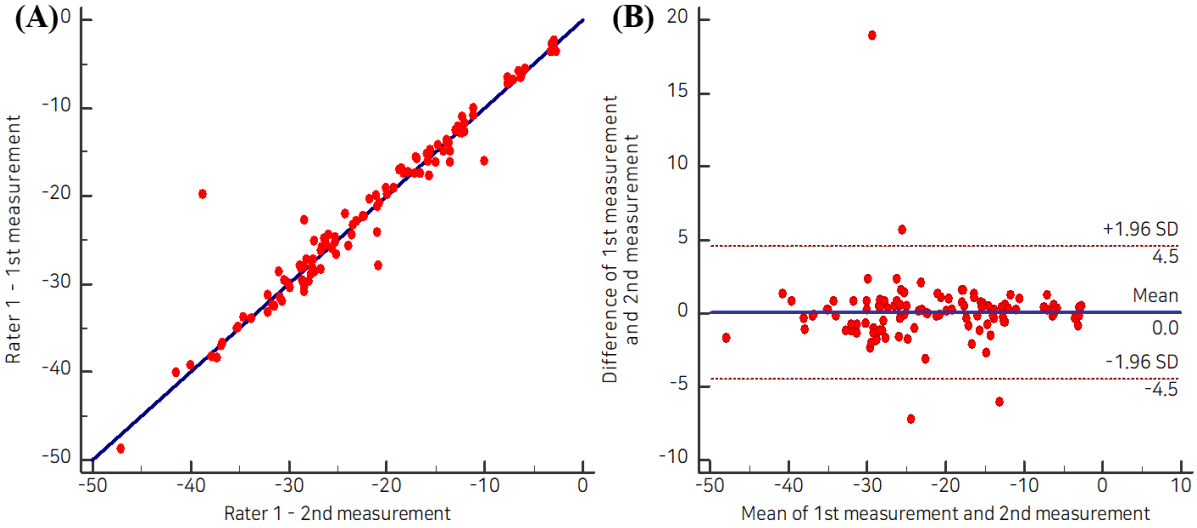

Figure 4. Agreement for the heel rise test loss (%) variables between sessions 1 and 2 of the Calf raise application in subjects (left: Correlation session 1 and 2; right: Bland-Altman test of sessions 1 and 2)

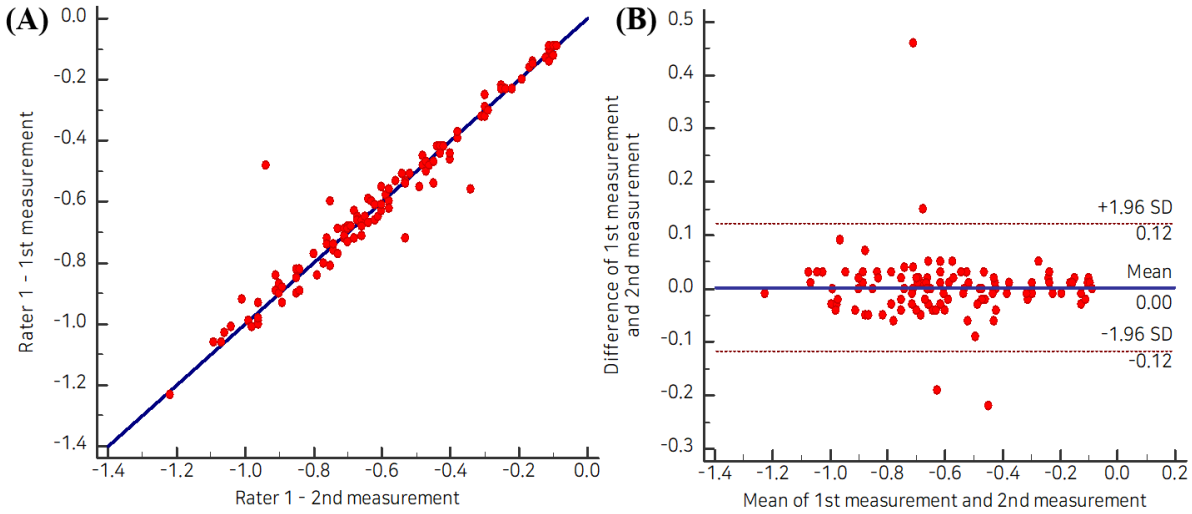

Figure 5. Agreement for the heel rise test slope variables between sessions 1 and 2 of the Calf raise application in subjects (left: Correlation session 1 and 2; right: Bland Altman test of sessions 1 and 2)

Table 4 lists the interrater reliability of the test–retest measurement in the calf raise application data. For the loss and slope values, the ICC was 0.946 (0.921–0.962) and 0.926 (0.893–0.949), which showed a high concordance rate. For each 95% LOA, the loss and slope values were –8.21 to 6.80 and –0.26 to 0.29, respectively, showing that the results were mostly symmetrical. The MDC% of each value was 2.85% and 0.11%, indicating that the absolute reliability between the test and retest was strong (Figures 6, 7).

DISCUSSION

This study examined the reliability and validity of an assessment of the heel-rise test using the 'Calf raise' application. In this study, the correlation with the application was compared with surface electromyography, used widely as the gold standard in muscle fatigue analysis. The intra-rater and inter-rater reliability of the calf raise application were measured. The Calf Raise application showed high reliability and validity.

Several evaluation methods and tools for the heel-rise test have been proposed. The existing evaluation tools used for the heel-rise test have low accessibility because of their complicated process and high cost. Some studies produced simple instruments for the heel-rise test to improve this limitation.

M haber et al. (2004) used an evaluation apparatus consisting of an adjustable rod, and a foot positioning device was used to limit each heel rise to the desired height (27). The height of the foot can be adjusted by placing the foot positioning device or rod in a preset hole, but fine adjustments are not possible, which may affect the height of the heel lift depending on the foot length and ankle movement. In addition, it is not safe if the participant loses balance during the test because the apparatus cannot be separated from the participants. After all, it is fixed to the forefoot.

Table 4. Inter-rater reliability using the 'Calf raise' application (n = 57)

	Session 1	Session 2	ICC (95%CI)	95% LOA	CV_{ME}%	MDC%
Loss (%)	-21.51±9.79[a]	-22.03±9.75	0.946 (0.921~0.962)	-8.21~6.80	0.14	2.85
Slope	-0.59±0.26	-0.61±0.27	0.926 (0.893~0.949)	-0.26~0.29	-0.16	0.11

[a]: mean ± standard deviation

ICC = intra correlation coefficient; *95% LOA* = 95% limits of agreements;

CVME% = coefficients of variation of method error %; *MDC%* = minimum detectable change %

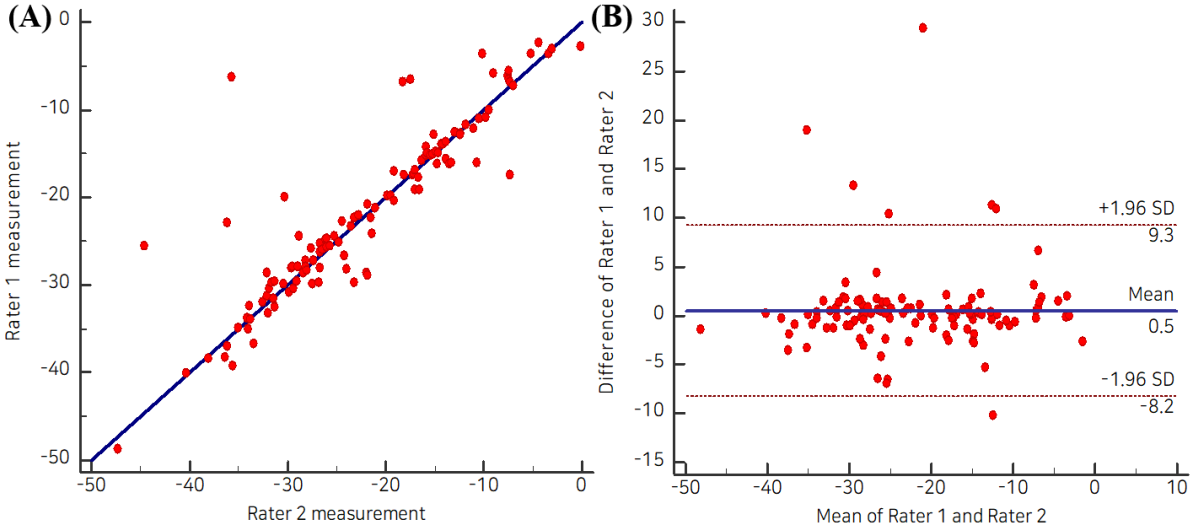

Figure 6. Agreement for the heel rise test loss (%) variables between rater 1 and 2 of the Calf raise application in subjects (left: Correlation rater 1 and 2; right: Bland-Altman test of rater 1 and 2)

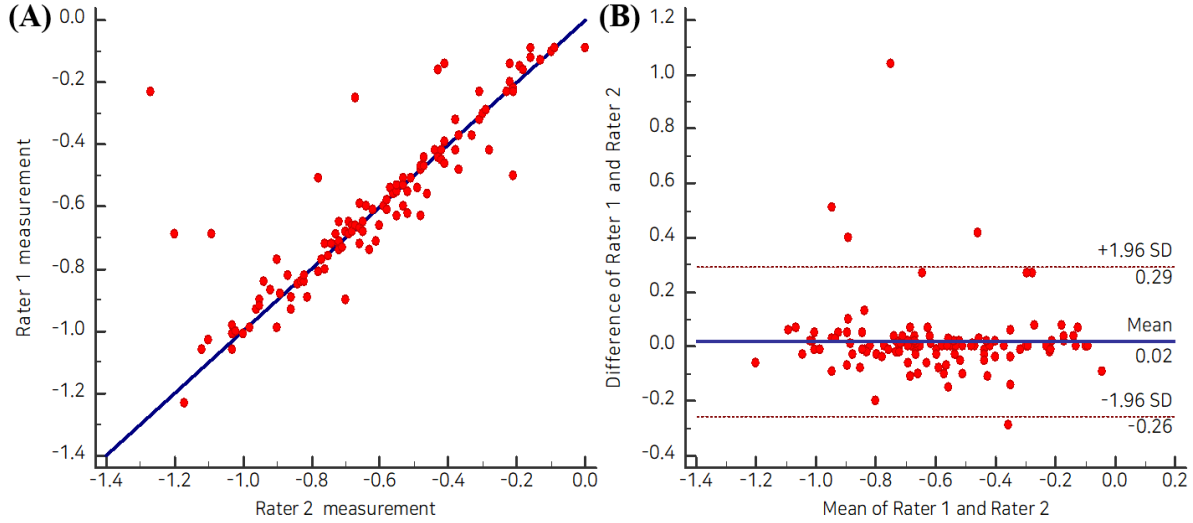

Figure 7. Agreement for the heel rise test slope variables between rater 1 and 2 of the Calf raise application in subjects (left: Correlation rater 1 and 2; right: Bland-Altman test of rater 1 and 2)

Sman et al. (2014) used a device that can adjust the position of the foot and the height of the heel for the heel-rise test (28). Compared to other devices, such as surface electromyography used to evaluate a plantar flexor, this device is easy to use and reasonably priced. On the other hand, it is difficult to observe the changes in heel height during a heel-rise test, and portability is poor in that it is necessary to carry the device for the test.

Yocum et al. (2010) used a device with a laser for the heel-rise test (29). Although it minimizes unnecessary external movements, it is difficult to standardize if the position of a foot is not accurate during the test, which may affect the result of the heel-rise test. In the case of the 'Calf raise' application used in this study, there is no additional cost required for manufacturing equipment, and accessibility and portability are also fine. In addition, the risk of injury is low, and it can be measured for clinical use considering the muscle fatigue of the plantar flexor. From the loss and slope with sEMG and Calf raise application, the Pearson correlation coefficient was used to confirm the change in muscle fatigue.

The Pearson correlation coefficient ‘r’ was 0.509, and the significance was $p<0.01$, showing a significant correlation between sEMG and the calf raise application. In addition, the test–retest of the

calf raise application showed an ICC (2,1) of the intra-rater reliability in the loss, and slope values were 0.986 (0.980–0.990) and 0.987 (0.981–0.991), respectively, showing high reliability. The intra-rater CVME% for the loss and slope values was -7.53% and -0.07%, respectively. The MDC was 0.75% for the loss and 0.01% for the loss and slope values, respectively, indicating high intra-rater reliability. In the interrater reliability, the ICC (2,1) for the loss and slope values was 0.946 (0.921–0.962) and 0.926 (0.893–0.949), respectively, showing high reliability. The interrater CVME% for the loss and slope values was 0.14% and -0.16%, respectively, and the corresponding MDC was 2.85% and 0.11%, showing high intra-rater reliability. Therefore, the calf raise application has good reliability for clinical use.

The limitation of this study was that people were excluded from the test because the height of the last heel lift was higher than the first heel lift, even though it provided feedback to produce the maximum muscle fatigue. In addition, it is difficult to generalize the results to people with musculoskeletal disorders because only ordinary people were assessed.

CONCLUSION

There was a high correlation between sEMG and the application when assessing the heel-rise test with high intra-rater and inter-rater reliability. Therefore, the 'Calf raise' application can show good clinical utility in assessing plantar flexor muscle performance and muscle fatigue, which are essential elements of gait and ADL.

APPLICABLE REMARKS

- This study finds that the Calf Raise application is a useful tool for measuring the muscle fatigue of the calf muscle.
- In the future, various measurement tools that are simple and can prove reliability will be needed.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Jun-Young Song, Myung-Mo Lee. Acquisition of data: Jun-Young Song, Byeong-Soo Kim. Analysis and interpretation of data: Sam-Ho Park, Byeong-Soo Kim, Myung-Mo Lee. Drafting the manuscript: Jun-Young Song. Critical revision of the manuscript for important: Sam-Ho Park, Byeong-Soo Kim. Intellectual content: Myung-Mo Lee. Statistical analysis: Sam-Ho Park, Myung-Mo Lee. Administrative, technical, and material support: Jun-Young Song, Myung-Mo Lee. Study supervision: Myung-Mo Lee.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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