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# Analysis of Knee Flexion Angles During 2 Clinical Versions of the Heel Raise Test to Assess Soleus and Gastrocnemius Function

**T**he increasing incidence rate<sup>38,48</sup> and associated high economic cost<sup>3</sup> of Achilles tendon disorders highlights the importance of performing an accurate and detailed clinical assessment of the triceps surae muscle-tendon unit. However, the assessment

of Achilles tendinopathies is challenging in orthopaedic clinical practice, because these conditions are commonly multifactorial in etiology,<sup>9</sup> have inconsistent nomenclatures,<sup>3</sup> and lack convenient clinical grading systems.<sup>27</sup> The initial management of Achilles tendon disorders is primarily conservative and regularly includes specific strengthening and stretching exercises targeting the triceps surae muscles (soleus and gastrocnemius).<sup>8,27,31</sup> As these muscles share a common distal insertion via the Achilles tendon but have distinct proximal origins at the knee, the exercises are usually prescribed in a greater and lesser degree of knee flexion to preferentially strengthen the monoarticular soleus and biarticular gastrocnemius, respectively.<sup>2,50</sup> In clinical practice, the heel raise test is frequently used to determine the effectiveness of such rehabilitative interventions,<sup>12,44,45</sup> and, like the rehabilitative exercises, the knee extension heel raise test (EHRT) and knee flexion heel raise test (FHRT) are employed to evaluate the gastrocnemius and soleus function, respectively.<sup>7,12</sup>

Optimally designed to assess the endurance of the triceps surae muscle-

● **STUDY DESIGN:** Controlled laboratory study, using a repeated-measures, counterbalanced design.

● **OBJECTIVES:** To provide estimates on the average knee angle maintained, absolute knee angle error, and total repetitions performed during 2 versions of the heel raise test.

● **BACKGROUND:** The heel raise test is performed in knee extension (EHRT) to assess gastrocnemius and knee flexion (FHRT) for soleus. However, it has not yet been determined whether select knee angles are maintained or whether total repetitions differ between the clinical versions of the heel raise test.

● **METHODS:** Seventeen healthy males and females performed maximal heel raise repetitions in 0° (EHRT) and 30° (FHRT) of desired knee flexion. The average angle maintained and absolute error at the knee during the 2 versions, and total heel raise repetitions, were measured using motion analysis. Participants' kinematic measures were fitted into a generalized estimation equation model to provide estimates on EHRT and FHRT performance applicable to the general population.

● **RESULTS:** The model estimates that average angles of 2.2° and 30.7° will be maintained at the knee by the general population during the EHRT and the FHRT, with an absolute angle error of 3.4° and 2.5°, respectively. In both versions, 40 repetitions should be completed. However, the average angles maintained by participants ranged from -6.3° to 21.6° during the EHRT and from 22.0° to 43.0° during the FHRT, with the highest absolute errors in knee position being 25.9° and 33.5°, respectively.

● **CONCLUSION:** On average, select knee angles will be maintained by the general population during the select heel raise test versions, but individualized performance is variable and total repetitions do not distinguish between versions. Clinicians should, therefore, interpret select heel raise test outcomes with caution when used to respectively assess and rehabilitate soleus and gastrocnemius function. *J Orthop Sports Phys Ther* 2011;41(7):505-513, Epub 18 February 2011. doi:10.2519/jospt.2011.3489

● **KEY WORDS:** Achilles tendon, ankle, triceps surae

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tendon unit, the heel raise test most commonly involves performing unilateral heel raises until fatigue.<sup>20</sup> Fatigue during the heel raise test has been defined as the inability to continue performing a “proper” heel raise,<sup>35</sup> where a decrease in performance can be observed by a reduction in heel raise height or pace, loss of balance or forward lean, or inability to maintain a defined knee position.<sup>21</sup> The total number of heel raise repetitions completed to this point is counted and used as the main clinical outcome measure.<sup>30</sup> Although primarily employed to assess endurance, the heel raise test is also used to assess the power, strength, and overall functional performance of the triceps surae muscle-tendon unit.<sup>21,30</sup>

In clinical practice and research,<sup>5,52</sup> the construct validity of utilizing 2 different knee positions to distinguish between the activities of soleus and gastrocnemius is supported by their respective anatomical insertions<sup>10</sup> and functional roles.<sup>43</sup> Electromyographic evidence demonstrates altered triceps surae muscle activity with a change in knee flexion position<sup>34,43</sup> and suggests a 30° increase from 0° as the minimal difference in knee flexion required to influence their relative contribution.<sup>10,34</sup> Many physical therapy procedures are performed in 0° and 30° of knee flexion to selectively assess or rehabilitate the 2 triceps surae muscles.<sup>7</sup> Because the muscle specificity of the heel raise test depends upon precise knee flexion angles, physical therapists need an evidence-based estimate of individuals’ ability to maintain select knee flexion angles, or of the amount of knee angle error, during the heel raise test to justify using 2 versions to distinguish between soleus and gastrocnemius function. This has not yet been researched or reported.

Common physical therapy measures and classification systems have been recently scrutinized,<sup>32,47</sup> and examining 2 clinical versions of the heel raise test is important to continue promoting evidence-based practice in orthopaedic and sports medicine. Differentiating between and selectively evaluating soleus and gas-

trocnemius with the heel raise test may aid physical therapists to further specify the etiology, pathogenesis, and musculoskeletal sequelae of Achilles tendinopathies,<sup>44</sup> as well to identify concurrent muscle injury or impairment<sup>51</sup> and to determine the most accurate clinical diagnosis, informed prognosis, and effective rehabilitation program.<sup>39</sup> It is, therefore, important to determine whether the key parameter suggested to differentiate the triceps surae muscles is maintained during the heel raise test, before further advocating specific use of 2 versions in clinical practice.

The aim of this study was to provide an estimate of the ability of a healthy population to maintain a 0° and a 30° knee flexion angle during an EHRT and an FHRT, respectively, by investigating the average knee angle maintained and the absolute angular error in knee flexion position during the 2 versions. Secondary objectives included determining the total number of heel raise repetitions completed, the degree of standardization of test parameters, whether fatigue (heel raise repetitions) influenced the ability of individuals to maintain select knee flexion angles, and whether outcomes were different between the EHRT and FHRT versions.

## METHODS

### Participants

A SAMPLE OF CONVENIENCE OF 17 healthy individuals (9 men and 8 women, aged 18 to 65 years) was recruited for the study. Exclusion criteria were a current or recent history of musculoskeletal injury and/or medical condition that could compromise the ability to perform maximal heel raise repetitions. All participants provided written informed consent prior to participation and their rights were respected. The study protocol was approved by The University of Otago Human Ethics Committee.

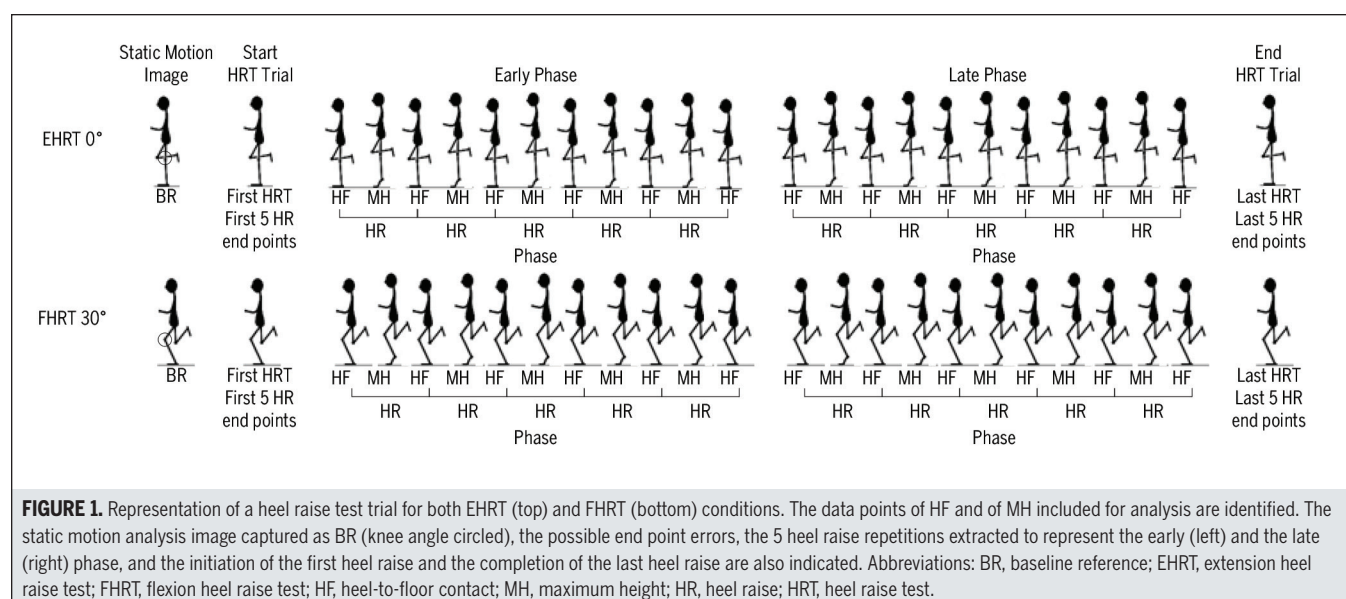
### Heel Raise Test

Each participant performed 2 clinical

versions of the heel raise test: (1) an EHRT in 0° knee flexion and (2) an FHRT in 30° knee flexion (**FIGURE 1**). The knee was positioned in 0°, with the tibia and femur aligned. A stratified randomization method ensured that the sequence of testing of the 2 heel raise test versions was balanced among sexes, and all tests were performed with the dominant lower limb, as determined by the Dunedin Footedness Inventory.<sup>40</sup>

Each participant’s knee was positioned following standard goniometry guidelines in 0° or 30°, using a long-arm goniometer (Fred Sammons Inc, Bissell Healthcare Corporation, IL). To facilitate balance during the heel raise test, participants were instructed to use minimal bilateral index fingertip support on an individually adjusted upright, which was positioned in front of them at shoulder height. The heel raise test instructions and parameters relating to heel raise height, pace, foot position, and balance support were based on those most frequently cited and utilized in the literature.<sup>20</sup> Stance foot placement and head position were standardized by positioning the first metatarsal on a predetermined floor marking and by focusing straight ahead on a visual target set at eye level. The nontested lower limb was free in space, in a position comfortable to participants, and allowed lower limb clearance during the heel raise test. An audible digital metronome (Sabine MT9000; Sabine Inc, Alachua, FL) was set at 120 beats per minute to standardize the pace at 60 heel raise repetitions per minute, with the heel lifting on the first beat and lowering to the floor on the second.

While standing on 1 foot, participants were instructed to “maintain the selected knee flexion position,” “perform as many heel raise repetitions as possible,” “lift the heel as high as possible during every raise,” “return the heel to the floor after each raise,” and “keep pace with the metronome.” They were reminded that the nontested limb should not contact the floor and to use the upright for



balance purposes only. During the test, the researcher provided verbal feedback to ensure that all instructions were followed and parameters standardized. The heel raise test was terminated when a participant could no longer lift the stance heel from the floor and/or repeat another heel raise. The primary goal of this study was to investigate the ability of individuals to maintain select knee flexion angles when performing heel raise repetitions to fatigue. The test was not terminated if a specified heel raise height threshold was not reached, if the set pace was momentarily lost, or if the balance support upright was inadvertently used to assist performance.

One full heel raise test trial was defined as the time from the initiation of the first heel raise until the completion of the last heel raise. The total number of heel raise repetitions performed within each trial was recorded (**FIGURE 1**), where “1 heel raise” was defined by 2 consecutive heel-to-floor contacts and included a data point for the maximal height of the heel during that repetition.<sup>19</sup>

## Kinematics

Sagittal plane kinematic data of lower limb motion were acquired using a 3-D motion analysis system incorporating 12 calibrated optoelectric cameras, sampling

at 100 Hz with Cortex, Version 1.1.4.368 software (Eagle EGL-500RT; Motion Analysis Corporation, Santa Rosa, CA). The angle data recorded from a retro-reflective set of markers placed over the lateral malleolus, lateral femoral condyle, and greater trochanter were used to represent the knee angle in degrees, and the distance between the marker positioned on the lateral malleolus and the ground calibration markers was computed to provide measures of heel raise height (mm).<sup>11</sup>

## Procedures

All participants attended a single session at a university biomechanics laboratory and were familiarized with all procedures prior to testing. Age, height, weight, and lower limb functional dominance (foot-*edness*)<sup>40</sup> were recorded. If a participant was classified as cross-dominant, the lower limb used to kick a ball was used for testing.<sup>23</sup>

Prior to data collection, the motion analysis system was calibrated for each individual. To reduce any initial motor learning effects, participants were allowed to practice the 2 heel raise test versions until they felt comfortable executing the 2 tasks.<sup>53</sup> Participants then performed a light warm-up on a stationary bicycle for 10 minutes, after which the

knee of the dominant lower limb was positioned in either 0° for the EHRT or 30° for the FHRT, according to the preallocated random sequence. A static motion analysis image was captured and used as a baseline reference to the initial knee angle and heel height positions, after which, participants performed either the EHRT or the FHRT until fatigue (**FIGURE 1**). A 40-minute rest was allocated between the heel raise test versions to allow recovery before the process was repeated, including warm-up, for the other version.<sup>42</sup>

## Data Processing

The kinematic data arising from the heel raise test were referenced to the baseline static motion image captured prior to the start of each heel raise test version. To eliminate possible end point errors, data were analyzed by excluding the first 5 and the last 5 heel raise repetitions.<sup>33</sup> The next 5 repetitions from the beginning of each heel raise test were extracted to represent the “early” phase, and the last 5 from the end to represent the “late” phase. The average angle maintained at the knee, recorded for the duration of the 5 repetitions within each phase, was computed, as was the time taken to perform them. The data collected at the moment of heel-to-floor and maximal height were then extracted for each repetition and

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used for subsequent analyses.<sup>24</sup> A schematic summary of the data reduction process is illustrated in **FIGURE 1**.

The amount of variability from the selected knee flexion angle during the heel raise test versions was determined by calculating the “absolute angular error” from every extracted heel-to-floor and maximal height data point.<sup>28</sup> The absolute differences between the knee flexion angles captured at baseline and heel-to-floor, as well as between the angles captured at baseline and maximal height, were calculated. The absolute differences of the 5 heel raise repetitions within each phase were averaged to define the absolute angular error of that phase. The absolute angular error of a phase, therefore, included a total of 11 absolute differences: 6 from baseline to heel-to-floor, and 5 from baseline to maximal height (**FIGURE 1**). The difference between the heights captured at baseline and at each maximal height, the duration of a phase divided by 5 repetitions (pace), and the total number of heel raise repetitions completed were derived from the motion analysis data set of each heel raise test and used to describe and analyze the outcomes of the heel raise test.

## Descriptive Data Analysis

Means, standard deviations, ranges (minimum to maximum), and ratios were calculated to report the demographic characteristics of the sampled cohort. Means and 95% confidence intervals (CIs) were computed for the kinematic data for the EHRT and FHRT. Data from the early and late phases were treated (1) separately to allow for comparison between the 2 phases and to infer the effects of fatigue on heel raise test performance, and (2) collectively (early and late) to provide a representation of the kinematic data for the entire duration of the EHRT and FHRT.

## Statistical Data Analysis

The influence of heel raise test version (EHRT/FHRT) and phase (early/late) on the (1) average angle maintained, (2)

absolute angular error, and (3) number of heel raise repetitions performed was estimated by using a generalized estimation equation (GEE). The GEE approach is employed when measures are correlated, such as when collected from the same individual at different time points,<sup>13–15,29</sup> and is promoted for use in sports medicine and orthopaedic research.<sup>18,41</sup> A GEE provides consistent estimates of the regressed parameters and applies robust standard errors to account for within-participant repeated measures. The regression coefficients ( $\beta$ ) from a GEE provide estimates on the amount of difference in the outcomes under the different conditions. The GEE estimates can be tailored to the distributional errors associated to specific exponential families, like considering the probable errors from a Poisson distribution when analyzing count variables.

The GEE model applied in this study used a Gaussian (normal) distribution when analyzing the average angle maintained and the absolute angular error, and Poisson (count) distribution for the number of heel raise repetitions. The GEE clustered within-participant measures and applied an exchangeable correlation structure, which assumed that the amount of correlation was equal between participants' measures. Regression coefficients ( $\beta$ ) were estimated from each GEE analysis, with the EHRT version and the early phase set as reference. Therefore, the regressed coefficients estimated the amount of difference in the outcomes from the FHRT compared to the EHRT,

and from the late compared to the early phase. The variables of heel raise height and pace were also fitted into the GEE model in a secondary analysis to confirm the extent of standardization of heel raise test parameters.

A significance level of  $P \leq .05$  was determined a priori for all analyses, which were performed using STATA Version 11.0 (StataCorp LP, College Station, TX).

## RESULTS

### Descriptive Analysis: Participants' Demographics and Heel Raise Test Performance

**A** TOTAL OF 17 PARTICIPANTS (9 MALES and 8 females; age range, 20 to 37 years) were tested and completed the 2 heel raise test versions. **TABLE 1** offers a descriptive summary of their demographic characteristics, and **TABLE 2** their kinematic outcomes of the EHRT and FHRT. The average angle maintained by participants at the knee was of 3.8° (range, –6.3° to 21.6°) during the EHRT and of 31.9° (range, 22.0° to 43.0°) during the FHRT. Their mean absolute angular error, or variation from the selected heel raise test knee angle, was 4.7° (range, 0.0° to 25.9°) and 6.5° (range, 0.0° to 33.5°) during the EHRT and the FHRT, respectively. Participants completed an average of 40 repetitions (range, 14 to 54) in both heel raise test versions. **FIGURE 2** illustrates the real-time measures of the knee flexion angle captured by the motion analysis system for a participant (selected at random) during the early and late phase for both the

**TABLE 1**

**DESCRIPTIVE STATISTICS\***

Demographic Characteristics	Participants (n = 17)	Males (n = 9)	Females (n = 8)
Age, y	25.6 ± 4.6 (20, 37)	27.7 ± 5.4 (20, 37)	23.4 ± 1.8 (21, 26)
Height, cm	172.4 ± 9.3 (160, 189)	177.0 ± 8.7 (165, 189)	167.3 ± 7.2 (160, 183)
Weight, kg	71.1 ± 10.0 (56.7, 94.8)	77.5 ± 8.0 (68.9, 94.8)	63.9 ± 6.6 (56.7, 73.8)
Body mass index, kg/m <sup>2</sup>	23.9 ± 2.4 (19.9, 28.3)	24.8 ± 2.2 (22.2, 28.3)	22.9 ± 2.3 (19.9, 27.7)
Footedness, left:right	2:15	1:8	1:7

\*Values are mean ± SD (minimum, maximum) and footedness ratios.



TABLE 2

DESCRIPTIVE STATISTICS\* OF THE AVERAGE ANGLE MAINTAINED, ABSOLUTE ANGULAR ERROR, REPETITIONS, HEEL RAISE HEIGHT, AND HEEL RAISE PACE BY HEEL RAISE TEST VERSION AND PHASE

Heel Raise Test Version/Phase	Average Angle Maintained, deg <sup>†</sup>	Absolute Angular Error, deg <sup>‡</sup>	Repetitions, n	Height, mm	Pace (Repetitions/min)
EHRT					
Early and late	3.8 (1.7, 5.9)	4.7 (4.2, 5.2)	40 (36, 45)	66.5 (64.4, 68.6)	59.1 (57.9, 60.4)
Early	2.2 (0.1, 4.2)	3.4 (3.0, 3.9)	...	73.1 (70.9, 75.3)	58.9 (57.5, 60.4)
Late	5.5 (1.8, 9.2)	5.9 (5.0, 6.9)	...	59.8 (56.8, 62.8)	59.4 (57.2, 61.6)
FHRT					
Early and late	31.9 (30.4, 33.5)	6.5 (5.9, 7.0)	40 (35, 47)	64.7 (62.4, 67.0)	60.3 (59.3, 61.3)
Early	30.7 (28.3, 33.1)	6.3 (5.5, 7.0)	...	70.1 (66.9, 73.3)	59.8 (58.8, 60.7)
Late	33.2 (31.2, 35.2)	6.7 (5.9, 7.5)	...	59.3 (56.3, 62.3)	60.8 (58.9, 62.7)

Abbreviations: EHRT, extension heel raise test; FHRT, flexion heel raise test.

\*Values are mean (95% CI).

<sup>†</sup>Values are the mean knee angle maintained during the 5 heel raise repetitions in each phase.

<sup>‡</sup>Values are from the differences between baseline reference to the data points of heel-to-floor contact and maximum heel raise height of the 5 heel raise repetitions from each phase.

EHRT and FHRT versions.

### Statistical Analysis: Average Angle Maintained, Absolute Angular Error, and Heel Raise Repetitions

The interaction between heel raise test version and phase had no significant influence on any of the variables analyzed ( $P \geq .141$ ). Consequently, no further analysis involving the interaction term was performed. Heel raise test version ( $P < .001$ ) and phase ( $P = .005$ ) both significantly influenced the average angle maintained during the heel raise test (TABLE 3). Heel raise test version ( $P < .001$ ) and phase ( $P = .010$ ) also had an effect on the absolute angular error (TABLE 3). No influence of test version ( $P = 1.000$ ) on the number of heel raise repetitions completed was observed (TABLE 3).

If a healthy individual performs the 2 selected versions of the heel raise test until volitional fatigue, the GEE results estimate that the average angle maintained will be of  $2.2^\circ$  in the early phase of the EHRT, with an absolute angular error of  $3.4^\circ$ , and that 40 repetitions will be performed ( $\beta_0$  in TABLE 3). The average angle maintained and absolute angular error during the FHRT will be  $28.5^\circ$  and  $2.8^\circ$  greater than when performed in EHRT, and the number of heel raise rep-

etitions performed will be similar to that in EHRT ( $\beta_1$  in TABLE 3). From the early to the late phase of the heel raise test, the average angle maintained is expected to increase by  $3.4^\circ$  and the absolute angular error by  $2.5^\circ$  ( $\beta_2$  in TABLE 3).

### Secondary Analysis: Heel Raise Height and Pace

A confirmatory GEE analysis demonstrated that heel raise height was only significantly influenced by test phase ( $P < .001$ ), with the regression coefficient estimating a decrease in height by 13.3 mm from the early to the late phase. In contrast, phase had no influence on pace ( $P = .588$ ), which is maintained over the duration of the heel raise test by healthy individuals.

## DISCUSSION

THE MAIN AIM OF THIS STUDY WAS TO provide an estimate on the ability of the general population to maintain select knee flexion angles during the heel raise test. The results from the GEE indicate that healthy individuals should be able to maintain defined knee flexion positions during the heel raise test at an acceptable level. With 95% confidence, individuals should perform the early

phase of an EHRT ( $0^\circ$ ) with the knee in  $0.3^\circ$  to  $4.0^\circ$ , and in  $27.6^\circ$  to  $33.8^\circ$  during an FHRT ( $30^\circ$ ). The 95% CI of the difference in the average angle maintained between the 2 selected versions ranged from  $25.4^\circ$  to  $31.6^\circ$  and included the  $30^\circ$  threshold reported to modify the relative activity of the triceps surae muscles.<sup>10,34</sup> Therefore, the muscle selectivity of the 2 heel raise test versions can also be considered acceptable, based on the estimated degree of knee flexion angle maintenance from the GEE analysis. However, some caution is advised, as the findings also indicate errors in select knee flexion position during the early phase of the EHRT ( $3.4^\circ$ ) and FHRT ( $6.2^\circ$ ) that increase in the late phase by  $2.5^\circ$ . Additionally, although the general population's ability to maintain select knee flexion angles is considered acceptable, individual performance of the 2 heel raise test versions is variable.

### Extent of Knee Angle Maintenance

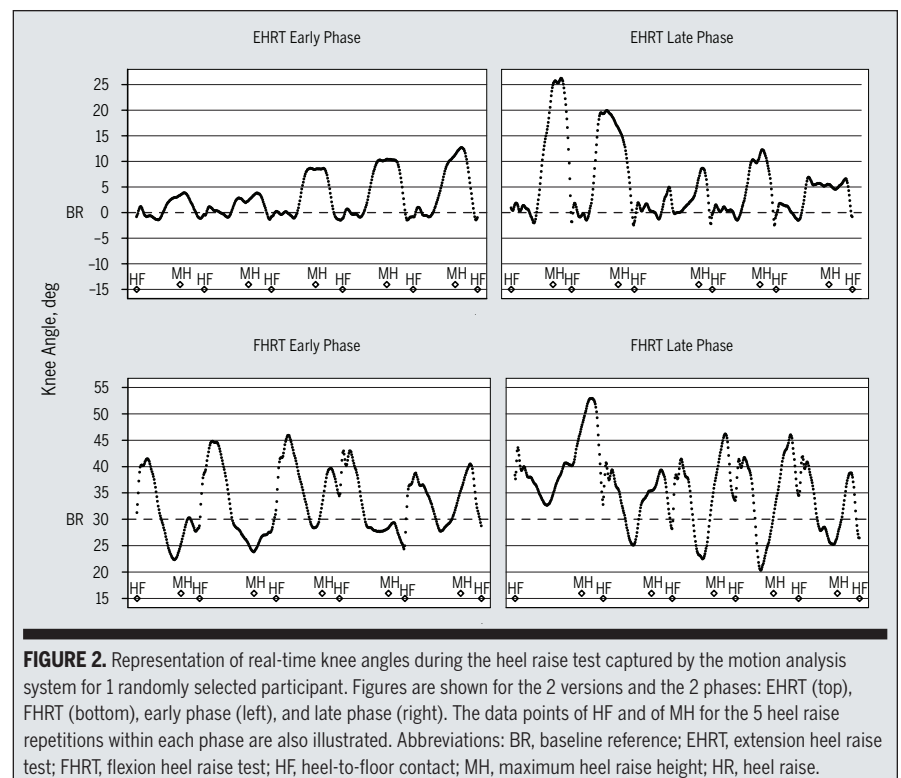
Select knee flexion angles are used to discriminate some of the functional properties of soleus and gastrocnemius, based on the accepted principle that modifying knee position alters the length of gastrocnemius while controlling soleus' length.<sup>10</sup> The extent to which the activi-

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ties of the triceps surae muscles are altered by knee flexion is inconsistently reported in EMG research.<sup>25,37</sup> However, most studies report the greatest amount of gastrocnemius activity when the knee is in approximately 0° of flexion.<sup>26,43,49</sup> When knee flexion increases, the muscle shortens, showing lower levels of EMG signal amplitudes and a decreased ability to recruit motor units.<sup>26</sup> Because select knee flexion angles are well maintained during the heel raise test, the relative activity of the triceps surae muscles during the test should also be maintained, which is in agreement with the proposed muscle selectivity of the 2 versions. However, the point estimate of the difference in the average angle maintained between the versions from our sample of healthy individuals was below the 30° threshold reported to alter the relative contribution of the triceps surae muscles.<sup>10,34</sup> The amount of absolute angular error during the EHRT (3.4°) and FHRT (6.2°), and increases in absolute angular error (2.5°) and average angle maintained (3.4°) with fatigue also need to be considered. As select knee flexion angles are not precisely maintained and the difference between the 2 versions may be less than the 30° threshold, further separating select knee flexion angles of 2 heel raise test versions at baseline (eg, the EHRT at 0° and the FHRT at 40° to 60°) is recommended to optimize their muscle specificity. Future studies that extend on, and explore beyond, motion analysis using other research strategies (eg, EMG) are required to further clarify the issue.

### Extent of Knee Angle Variability

The ability to maintain knee flexion angles during the heel raise test is generally accepted; but clinicians need to consider individual variability in performance. Within the sampled cohort, the average angle maintained ranged from -6.3° to 21.6° in the EHRT and from 22.9° to 43.0° in the FHRT. The maximum absolute angular error in the 2 versions was 25.9° and 33.5°, respectively. This range of variability demonstrates that the abil-



**FIGURE 2.** Representation of real-time knee angles during the heel raise test captured by the motion analysis system for 1 randomly selected participant. Figures are shown for the 2 versions and the 2 phases: EHRT (top), FHRT (bottom), early phase (left), and late phase (right). The data points of HF and of MH for the 5 heel raise repetitions within each phase are also illustrated. Abbreviations: BR, baseline reference; EHRT, extension heel raise test; FHRT, flexion heel raise test; HF, heel-to-floor contact; MH, maximum heel raise height; HR, heel raise.

ity to maintain select knee flexion angles depends upon the individual performing the test, with consequences on the proposed muscle selectivity of 2 heel raise test versions. Thus, when an individual has difficulty maintaining select knee flexion angles, physical therapists should not use 2 heel raise test versions to distinguish between soleus and gastrocnemius function.

### Number of Heel Raise Repetitions

The results of this study suggest with 95% confidence that individuals perform 36 to 45 repetitions during the heel raise test, with no difference between the EHRT and FHRT versions. This finding may indicate that there is no significant change in, or selective recruitment of, gastrocnemius and soleus function between heel raise test versions performed in 0° and 30°. As suggested above, the estimated 28.5° difference in the average angle maintained during these 2 versions may be too small, and the amount of absolute angular error and variability in knee flexion position too great, for clini-

cal soleus and gastrocnemius differentiation. However, many factors affect the number of repetitions completed during successive heel raise repetitions<sup>19,36</sup> and, although similar numbers of heel raises in both heel raise test versions were estimated and observed, performance may rely on different triceps surae muscle recruitment patterns or synergistic behaviors.<sup>46</sup> Physical therapists may be able to identify an individual with an impaired function of the triceps surae muscles if the clinical outcomes of 2 select heel raise test versions are different or if they are not within the range of 36 to 45 repetitions estimated from this cohort. Comparing the outcomes of 2 heel raise test versions could be a useful means of quantifying the amount of triceps surae muscle dysfunction, assessing the effect of intervention programs during rehabilitation, and screening for potential injury risk factors. More clinical studies are warranted.

### Early and Late Phases

The data were divided into 2 phases to

TABLE 3

GEE ANALYSIS OF THE OUTCOME VARIABLES  
ACCORDING TO THE EXPLANATORY VARIABLES  
OF HEEL RAISE TEST VERSION AND PHASE\*

Outcome Variables	Intercept ( $\beta_0$ )	Version ( $\beta_1$ )	Phase ( $\beta_2$ )
Average angle maintained, deg	2.2 (0.3, 4.0), $P = .025^{\dagger}$	28.5 (25.4, 31.6), $P < .001^{\dagger}$	3.4 (1.0, 5.7), $P = .005^{\dagger}$
Absolute angular error, deg	3.4 (2.4, 4.4), $P < .001^{\dagger}$	2.8 (1.4, 4.2), $P < .001^{\dagger}$	2.5 (0.6, 4.4), $P = .010^{\dagger}$
Repetitions <sup>‡</sup>	40.4 (36.3, 44.9), $P < .001^{\dagger}$	1.0 (0.9, 1.1), $P = 1.000$	...

\*The regression coefficients (95% confidence interval) of the intercept ( $\beta_0$ ), version ( $\beta_1$ ), and phase ( $\beta_2$ ), and levels of significance (P) are reported. Results based on a GEE model using the 0° knee flexion version and the early phase of the heel raise test as a reference.

<sup>†</sup>Significance level  $P < .05$ .

<sup>‡</sup>Exponential function ( $e^x$ ) applied to the regression coefficients.

determine the effect of triceps surae muscle fatigue on heel raise test performance, considering that muscle fatigue decreases performance and increases the risks of sporting injury.<sup>17,22</sup> With heel raise repetitions, the ability to maintain select knee flexion angles declines, as indicated by the estimated 3.4° rise in the average angle maintained and the 2.5° increase in the absolute angular error. However, whether these changes are clinically relevant and indicate triceps surae muscle fatigue during the heel raise test cannot be determined by these findings alone, particularly because research on the ability of individuals to match a defined knee flexion position in weight bearing suggests that a 2.5° absolute angular error in active repositioning prior to fatigue is “normal.”<sup>6,16,28</sup>

Many studies have used the reduction in heel raise height as an indicator of triceps surae muscle fatigue and a termination criterion for the heel raise test, and, recently, as a measure of decreased triceps surae muscle-tendon unit function.<sup>20,45</sup> The confirmatory GEE analysis supports these practices, estimating a 13.3-mm drop in heel raise height from the early to the late phase ( $P < .001$ ), which demonstrates a decline in heel raise test performance.<sup>35</sup> This is the first study to provide an estimate of the amount of variation in heel raise height during 2 heel raise test versions when individuals are instructed to attempt maximum heel raise height during each raise and the test is not terminated if a certain height is not

reached. Documenting the extent of decrease in heel raise height in a clinical setting would be an additional method of quantifying heel raise test performance. However, physical therapists currently have limited access to equipment that might provide an accurate measurement of heel raise height; therefore, precise clinical quantification during the heel raise test may be difficult.

### Clinical Considerations

Sports and orthopaedic physical therapists use outcomes from 2 heel raise test versions to quantify the function of soleus and gastrocnemius and to determine the most appropriate rehabilitation program for treating disorders of the triceps surae muscles and Achilles tendon.<sup>12,30,44,52</sup> Our research findings offer physical therapists robust estimates on the average angle maintained, the absolute angular error, and the number of repetitions completed during 2 heel raise test versions. Although the results suggest that select angles used to distinguish the triceps surae muscles during the heel raise test are, on average, well maintained, there is error in knee flexion position, individual performance is variable, and the total number of heel raises completed is similar. Utilizing 2 versions of the heel raise test is time consuming and may not be required in all clinical assessment procedures, nor to distinguish triceps surae muscle function in individuals unable to maintain select knee flexion positions. For the purposes of efficiency

and increased accuracy, the EHRT may be recommended over the FHRT for evaluating the triceps surae muscles, as the version appears easier to standardize. The EHRT has a higher consistency in knee flexion angles and a smaller error in knee flexion position, and it is well established by EMG research to recruit higher levels of gastrocnemius activity. A similar rationale may be extended to rehabilitation and exercise prescription. Because the 2 forms of eccentric exercises prescribed for Achilles tendon disorders and the 2 heel raise test versions investigated in this study are of a similar construct,<sup>1,50</sup> prescribing both forms may not be required. The lack of an appreciable difference in the number of repetitions and the potential equal contribution of the triceps surae muscles towards heel raise performance in the 2 heel raise test versions need to be further investigated, as these could have important clinical rehabilitation implications, particularly in exercise prescription.

### Limitations

Generalizations of the results are limited to the specific heel raise test parameters used and the instructions provided in this study, healthy individuals with no current or recent history of musculoskeletal and/or medical condition, and kinematic analysis in the sagittal plane of a basic lower limb marker set.

Musculoskeletal injuries or impairments have been shown to have a detrimental influence on the kinematics of, and the ability to perform, a heel raise repetition.<sup>4</sup> Consequently, the presence of pathological musculoskeletal conditions will most likely have a negative impact on the ability to maintain select knee angles during the heel raise test and the number of successive heel raise repetitions performed. Although our estimates on heel raise test performance are applicable to a general population without known pathology or injury, it is unknown whether these results can be generalized to older individuals. Therefore, further research is required, as these estimates may change

with population groups or with different clinical presentations.

Although EMG investigative strategies could have been employed, clinicians do not frequently have access to, or use, EMG equipment for the assessment of the triceps surae muscles. In contrast, sagittal plane motion is measurable and visually observable. Therefore, a basic set of 3 retroreflective markers was used to determine whether individuals could maintain knee flexion angles. Further biomechanical investigation of the EHRT and FHRT, using EMG strategies, is recommended.

## CONCLUSION

**P**HYSICAL THERAPISTS ADMINISTER the heel raise test in 2 select knee flexion positions to assess gastrocnemius and soleus function. The current study indicates that, on average, healthy individuals maintain knee angles during the heel raise test. This suggests that using select heel raise test versions to assess soleus and gastrocnemius function is an acceptable clinical practice. However, clinicians should consider that errors in knee flexion position occur during testing, individual performance is variable, and total repetitions performed do not distinguish between heel raise test versions. Caution is advised during the interpretation and comparison of select heel raise test outcomes, as the relative contribution of the triceps surae muscles to performance may potentially be equal in the different clinical versions of this test. ●

## KEY POINTS

**FINDINGS:** Select knee flexion angles considered to differentiate gastrocnemius and soleus function during the heel raise test can be reasonably well maintained, based on estimates derived from a cohort of healthy individuals. However, individual performance is variable, errors in knee position occur during testing, and the number of repetitions completed in the select heel raise test versions does not allow differentiation

of the 2 versions.

**IMPLICATIONS:** Given the estimated variability in knee position, the range of individualized heel raise test performance, and the similar number of repetitions completed, caution is advised when using and interpreting outcomes of select heel raise test versions.

**CAUTION:** These research findings were derived from motion analysis and clinical measures of 2 heel raise test versions performed by a cohort of healthy individuals following standard test parameters and instructions.

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