The Foot 60 (2024) 102112

Contents lists available at ScienceDirect

The Foot

journal homepage: www.elsevier.com/locate/foot

A randomised crossover trial on the effects of foot starting position on calf raise test outcomes: Position does matter

Kim Hébert-Losier [a,*,1,2], Ma. Roxanne Fernandez [a,b,3,4], Josie Athens [c,5], Masayoshi Kubo [d,6], Seth O'Neill [e,7,8]

[a] Division of Health, Engineering, Computing and Science, Te Huataki Waiora School of Health, University of Waikato, Tauranga, New Zealand
[b] Department of Physical Therapy, College of Rehabilitation Sciences, University of Santo Tomas, Philippines
[c] Systems Biology Enabling Platform, AgResearch Ltd, Invermay Agricultural Centre, 176 Puddle Alley, Mosgiel 9022, New Zealand
[d] Department of Physical Therapy, Niigata University of Health and Welfare, Japan
[e] School of Healthcare, Life Sciences, University of Leicester, United Kingdom

ARTICLE INFO

Keywords:
Ankle
Endurance
Heel-rise test
Plantar flexion
Rehabilitation
Triceps surae

ABSTRACT

Background: This randomised crossover study with repeated measures examined the influence of the three most common foot starting positions used in conducting the calf raise test (CRT) on test outcomes. This study also accounted for the potential influence of gender, age, body mass index (BMI), and level of physical activity on test outcomes.

Methods: Forty-nine healthy individuals (59 % female, 21 ± 4 years) performed single-leg calf raise repetitions in a human movement laboratory in three randomised foot starting positions: flat, 10° incline, and step. The validated Calf Raise application was used to track the vertical displacement of a marker placed on the foot using computer vision. The application extracted the following CRT outcomes from the vertical displacement curve: number of repetitions, peak vertical height, total vertical displacement, and total positive work. Data were analysed using mixed-effects models and stepwise regression.

Results: There was a significant main effect ($P < 0.001$) of foot starting position on all outcomes, with all paired comparisons being statistically significant ($P \leq 0.023$). Repetitions, total vertical displacement, and total positive work were greatest in flat and lowest in step, whereas peak vertical height was greatest in incline and lowest in step. Gender ($P = 0.021$; males>females) and BMI ($P = 0.002$; lower BMI>higher BMI) significantly influenced the number of repetitions. Gender ($P < 0.001$; males>females) also influenced total positive work. Age and physical activity levels did not significantly influence CRT outcomes.

Conclusions: CRT foot starting position mattered and significantly affected all CRT outcomes. CRT foot starting position needs consideration when contrasting data in research and practice.

1. Introduction

The calf raise test (CRT) was introduced in the 1940s as a clinical method for measuring triceps surae (TS) muscle function (i.e., strength and endurance) [1,2]. The CRT remains a standard assessment tool in clinical practice and research [3] and is used to assess functional abilities in varied populations, including children [4], elderly [5], and individuals with musculoskeletal [2,6] and medical [7,8] conditions. The

* Corresponding author.
E-mail addresses: kim.hebert-losier@waikato.ac.nz (K. Hébert-Losier), rlfernandez@ust.edu.ph (Ma.R. Fernandez).
1 ORCiD: https://orcid.org/0000–0003-1087–4986
2 Twitter: @KimHebertLosier
3 ORCiD: https://orcid.org/0000–0003-0417–3817
4 Twitter: @XanneFernandez
5 ORCiD: https://orcid.org/0000–0002-9897–0683
6 ORCiD: https://orcid.org/0000–0002-8333–0251
7 ORCiD: https://orcid.org/0000–0002-0904–1381
8 Twitter: @Seth0Neill.

https://doi.org/10.1016/j.foot.2024.102112
Received 14 April 2024; Received in revised form 12 June 2024; Accepted 15 June 2024
Available online 17 June 2024
0958-2592/

CRT involves standing on one leg and performing repeated concentric and eccentric plantarflexion contractions until fatigue (i.e., volitional cessation), with the number of repetitions completed recorded as the primary clinical outcome [1]. Other CRT metrics, such as peak height and work, are considered key objective outcomes of the TS function in Achilles tendon rupture rehabilitation research [2,9,10] as they are more sensitive in detecting functional impairments than the number of repetitions [2,9]. The CRT is not only used to monitor Achilles tendon rupture rehabilitation [11], but it is also used to examine and compare the influence of various treatment strategies (e.g., surgical vs functional rehabilitation) [12], induce fatigue of the extrinsic foot core muscles [13], and to build TS strength endurance when prescribed as an exercise [14].

Despite its common use, there is no consensus protocol used to administer the CRT [3] and the majority of studies only report repetitions completed. This inconsistency in protocol may contribute to the variable normative CRT values reported across studies [1,15–17]. Consequently, clinicians and researchers may have difficulty interpreting outcomes and deciding on what parameters to implement in practice. Hence, it is imperative to understand how changes in parameters affect CRT outcomes to promote evidence-based practice. One CRT parameter that varies in practice and research is the foot starting position [3]. The CRT has been performed from plantigrade (0^{o} dorsiflexion) from a flat surface or floor [1,4], 10° dorsiflexion with an incline platform [9], or near maximal dorsiflexion with the forefoot on the edge of a step [18]. Due to the length-tension relationship, these variations are expected to alter TS muscle force production, with an increase in plantarflexion force as dorsiflexion range increases [19–21]. This change might result in a greater number of repetitions achieved during the CRT. Conversely, the increased range of motion with increased dorsiflexion may cause earlier TS muscle fatigue due to greater mechanical work [22], leading to fewer CRT repetitions. Hence, CRT outcomes may differ depending on foot starting positioning. Previous literature reporting normative values and using the CRT for various clinical populations may need revisiting when interpreted in light of potential differences arising from foot positioning.

We aimed to examine the influence of foot starting position on CRT outcomes, namely the number of repetitions, total vertical displacement, peak vertical height, and total positive work. The goal was to compare the three most common foot starting positions used to conduct the CRT: flat (0^{o}), incline (10^{o} dorsiflexion), and step (forefoot supported). Due to the increased range of motion and mechanical work required per repetition when dorsiflexion is increased, we hypothesised fewer repetitions in step than incline than flat conditions. Since CRT performance can differ between genders [5,15,16,23,24] and decrease with age [5,15,16,23,24], body mass index (BMI) [15,23], and lower physical activity levels [5,15,23], a secondary objective was to account for the potential influence of these predictors on CRT outcomes.

2. Material and methods

2.1. Sample size

Based on one-sample comparison of means and setting the minimal detectable change between conditions to six repetitions from published test-retest data [10], the estimated required sample size using G*Power 3.1.9.7 was 43 to attain 90 % power at a 5 % significance level assuming a mean and standard deviation of 32 ± 12 repetitions [10]. To account for 10 % of missing data, 48 participants were targeted.

2.2. Study design

A randomised crossover study with repeated measures was used to examine the effect of varying foot starting position (i.e., flat, incline, and step) on the following CRT outcomes: number of repetitions, total vertical displacement, peak vertical height, and total positive work. We also accounted for the following predictors in the analysis: gender, age, BMI, and physical activity levels based on International Physical Activity Questionnaire (IPAQ) short form scores [25]. The extension to randomised crossover trial Consolidated Standards of Reporting Trials (CONSORT) 2010 statement was followed in reporting our study [26]. No changes to the planned trial or measured outcomes were made after study commencement. As only healthy individuals were recruited, the study and protocol were not pre-registered.

2.3. Participants

Through targeted online distribution lists and word-of-mouth, we recruited 49 healthy individuals from the local University campus. Participants had to be at least 16 years old, able to follow simple instructions, and able to perform repeated single-leg calf raises. We excluded participants with injuries, previous Achilles tendon ruptures, or conditions that would interfere with CRT performance. Before participation, participants were informed verbally and in writing about the study and potential risks involved with participation, such as delayed onset muscle soreness. All participants signed an informed consent document. The Human Research Ethics Committee of the University of Waikato approved this study (HREC2020#11), which followed the Declaration of Helsinki. Personally identifiable information obtained from participants was coded to preserve anonymity and confidentiality. All data were stored in keeping with university policies on data protection and research governance.

Prior to testing, baseline measurements were recorded, and participants completed a self-administered IPAQ short form questionnaire to classify their physical activity levels as low, moderate, or high [25]. Furthermore, participants were asked, “Which foot do you use to kick a ball?” to determine their leg dominance [27]. A stadiometer (seca model 0123) and scale (seca model ESE813) were used to record body height and mass of participants barefoot to the nearest 0.1 cm and 0.01 kg, respectively.

2.4. CRT protocol

All CRT were performed barefoot on either the dominant or non-dominant leg (allocated at random upon arrival for testing). The CRT was conducted three times on three separate occasions seven days apart in one of the following randomised foot starting positions allocated in a block-randomised order upon arrival for testing: flat (0^{o} dorsiflexion), incline (10^{o} dorsiflexion), and step (full dorsiflexion). Individuals completed their three test occasions on the same leg. Trained physiotherapists conducted all the tests in the same university movement laboratory, with the block randomisation performed by one of the researchers not involved in data collection. Blinding of participants and assessors was not possible due to the nature of the intervention. To warm-up, participants performed 10 double-leg calf raises from the ground at 60 beats per minute (30 calf raises per minute), guided by a metronome. Participants then completed three single-leg repetitions in their allocated foot starting position for a given session to ensure the CRT condition was performed appropriately. Two-minute rest was provided after the warm-up before formal experimentation.

Written and verbal instructions were provided to participants before CRT experimentation. Participants stood on one leg with the knee straight on one of three steel platforms constructed for this study, either flat (0^{o} dorsiflexion), incline (10^{o} dorsiflexion), or step (forefoot supported). Participants were instructed to bend their non-tested leg to 90^{o} knee flexion with their foot behind them. Participants were allowed to place two fingertips of each hand on the wall in front of them at shoulder height to assist with balance. They were instructed to perform as many repetitions as possible. They needed to raise the heel as high as possible and return to the start position for each repetition whilst keeping the knee of the test leg straight. Participants were instructed to go “all the way back down” in all conditions, including the step condition to encourage full range of dorsiflexion motion. Participants performed the test at a frequency of 30 calf raises per minute, guided by a metronome set to 60 beats per minute. Verbal encouragement was provided at regular intervals throughout the test. Finally, the CRT was stopped when participants could not maintain the pace, bent their test leg knee, moved forward rather than upward, applied more than their fingertips to maintain balance, or stopped due to fatigue (i.e., volitional cessation). Two attempts to correct CRT form was allowed prior to test cessation.

2.5. Equipment

The CRT outcomes were recorded using the validated Calf Raise application (CR_{app}) [28] that uses computer-vision algorithms to track the vertical displacement of a marker placed on the foot following calibration to a known distance on the screen [18,28,29]. During testing, the CR_{app} was used to record videos at a sampling rate of 60 Hz on one iPad Air device running iOS 14.1 (Apple, Inc., Cupertino, CA, USA). The iPad was positioned 30 cm from the side of the tested foot on a metal stand, which enabled the entire movement to be captured. To track the vertical displacement during the CRT, a round black sticker sized 24 mm was placed below the lateral malleolus. The test setup is illustrated in Fig. 1.

To derive CRT outcomes, the recorded body mass of individuals was entered into the application and the application was calibrated to the diameter of the 24 mm round sticker placed on the foot of participants. The computer-vision algorithms then tracked the vertical displacement of the marker over time from the video recordings, where the initial marker position in the first video frame defines a zero vertical position. From the position curve, the following outcomes were extracted: number of repetitions (n); peak vertical height (cm) defined as the maximum height of a single repetition from the initial position; total vertical displacement (cm) defined as the sum of all positive displacement, and total positive work (J) computed as the product of body mass, gravitational acceleration (9.81 m/s^2) and total vertical displacement. The total positive work here reflects the total mechanical work completed during the concentric phase of the CRT.

The application has demonstrated good-to-excellent validity of the recorded outcomes against 3D motion capture and force plate data (intraclass correlation coefficient $\geq$ 0.963, coefficient of variation $\leq$6.9 %) [18,29]. The CR_{app} has also demonstrated good-to-excellent inter-rater, intra-rater, and test-retest reliability [18,29].

2.6. Statistical analyses

We used mixed-effects models (i.e., Poisson for repetitions and linear models for peak vertical height, total vertical displacement, and total positive work) to examine the effect of foot starting position on CRT outcomes, accounting for age, gender, BMI, and physical activity levels. Further, upon checking the normality and heteroscedasticity of data, all continuous outcomes were log-transformed to decrease the observed heteroscedasticity. Hence, the estimates from the linear mixed-effects models represent rate ratios.

In our models, participants were treated as nested random factors to deal with the mixed-effects sampling scheme generated by individuals being exposed to all three CRT conditions. In addition, gender, age, BMI, and physical activity levels were entered as fixed factors. As a reference for comparison, the flat (0° dorsiflexion) foot position and male gender were set as reference for comparisons. The mixed-effects models were able to address incomplete data. The mixed-effects framework accommodates for this variability by incorporating random effects, which allows for estimation and consideration of within-subject differences despite missing data for a given participant.

In stepwise regression, non-significant predictors were sequentially removed from the initial model using the Bayesian information criterion, maintaining the foot starting position factor. In post-hoc comparisons, 95 % confidence intervals [lower, upper] and P-values were adjusted with the multivariate t-test distribution. The alpha level for all statistical analyses was set a priori to $P < 0.05$. All data were processed and analysed using R Core Team (2021) version 4.1.1 (2021–08-10) [30], and the *lme4* package for mixed-effects models [31].

3. Results

3.1. Participants

All forty-nine recruited participants completed the study (29 females and 20 males) and were aged 19 to 41 years. Their demographic data are presented in Table 1. Their physical activity levels ranged from moderate to high, with no participant presenting with low physical activity levels. None of the participants were experiencing delayed onset muscle soreness on their test leg when reporting for their subsequent experimental session. All participants completed at least two of the three testing sessions, but not all completed all three conditions (Table 2). All available data were analysed.

3.2. CRT outcomes

Table 2 presents the CRT outcomes for each foot starting position. Results from the mixed-effects models are shown in Table 3, with foot starting position influencing the four CRT outcomes ($P < 0.001$). Post-hoc comparisons revealed that all paired comparisons were statistically significant (Table 4, $P \leq 0.023$). Finally, Fig. 2 illustrates the

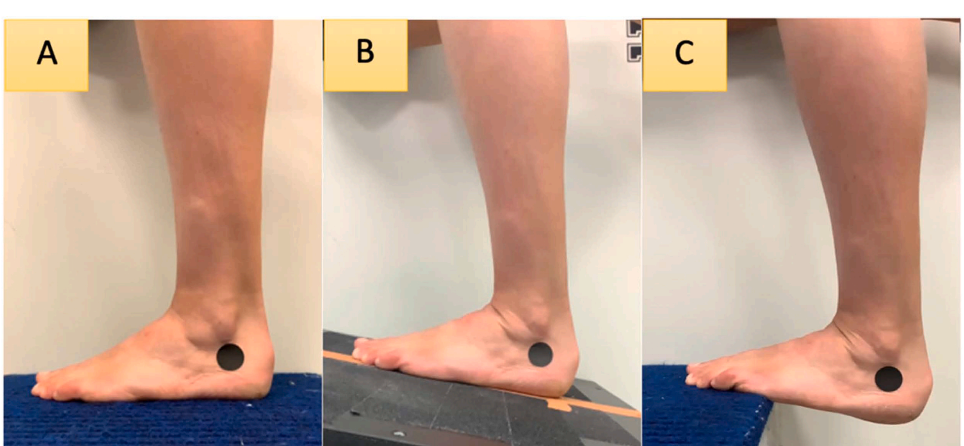

Fig. 1. Calf raise test experimental set-up. a. Flat (0° dorsiflexion); b. Incline (10° dorsiflexion); c. Step (forefoot supported).

Table 1
Demographic characteristics of the 49 participants as mean ± standard deviations.

Participants			
Characteristics	Male	Female	All
	$n = 20$	$n = 29$	$n = 49$
Age (y)	20 ± 2	22 ± 5	21 ± 4
Height (cm)	182 ± 8	168 ± 6	174 ± 10
Mass (kg)	89 ± 21	69 ± 10	77 ± 18
BMI (kg/m^2)	27 ± 5	24 ± 3	25 ± 4
IPAQ low, moderate, high (*n*)	0, 4, 16	0, 8, 19	0, 12, 35

Notes. Physical activity levels of participants based on IPAQ. Data for IPAQ missing from two participants.
Abbreviations. BMI, body mass index; IPAQ, International Physical Activity Questionnaire.

effects of the three starting positions and predictors on the CRT outcomes.

The number of repetitions completed was significantly greater in the flat, followed by incline and step position (Table 3, Fig. 2A). In addition, males performed more repetitions than females ($P = 0.021$), as did individuals with lower BMI (P=0.002, Table 3, Fig. 2A).

Similar to repetitions, total vertical displacement and total positive work were significantly greater in flat followed by incline and step ($P < 0.023$, Table 3, Fig. 2B, D). Moreover, males performed more work than females (Table 3, Fig. 2D). Foot starting position also significantly influenced peak vertical height, with the greatest height seen in the incline position followed by flat and step ($P \leq 0.002$, Table 3, Fig. 2C).

3.3. Predictors

Other than gender and BMI significantly influencing the number of repetitions, and gender influencing total positive work (Table 3); predictors did not significantly influence CRT outcomes and were removed from corresponding mixed-effects models during stepwise regression. Specifically, age and physical activity levels did not significantly influence any of the CRT outcomes and were hence removed from all mixed-effects models during stepwise regression.

4. Discussion

This study clearly illustrates differences in CRT outcomes between the three most common foot starting positions, thus supporting the hypothesis that altering foot starting position affects the number of repetitions, total vertical displacement, peak vertical height, and total positive work. In addition, gender and BMI significantly affected CRT repetitions and gender affected total positive work, whereas age and physical activity level did not influence any of the CRT outcomes in our population.

Table 2
Descriptive summary of calf raise test outcomes as means ± standard deviations by foot starting position from 49 participants.

Outcomes	Flat (0°DF)	Incline (10°DF)	Step (FFS)
	$n = 43$	$n = 48$	$n = 46$
Repetitions (*n*)	28 ± 8	22 ± 7	18 ± 8
Total vertical displacement (cm)	229 ± 70	211 ± 70	159 ± 80
Peak vertical height (cm)	9.14 ± 1.18	10.86 ± 1.36	8.44 ± 1.87
Total positive work (J)	1706 ± 608	1571 ± 599	1165 ± 572

Notes. Not all 49 participants completed the three positions, as indicates the *n* presented under each position.
Abbreviations. DF = dorsiflexion. FFS = forefoot supported.

Table 3
Mixed-effects models that considered foot starting position, age, gender, BMI, and physical activity levels on CRT outcomes.

CRT outcomes	Variables	Estimates* [95 % *CI*]	*P*-value
Repetitions (*n*)	*Positions*		< 0.001
	Flat (0°DF)	-	
	Incline (10°DF)	0.77 [0.70, 0.83]	
	Step (FFS)	0.61 [0.56, 0.67]	
	Gender		0.021
	Male	-	
	Female	0.83 [0.71, 0.97]	
	BMI	0.97 [0.95, 0.99]	0.002
Total vertical displacement (cm)	*Positions*		< 0.001
	Flat (0°DF)	-	
	Incline (10°DF)	0.88 [0.81, 096]	
	Step (FFS)	0.61 [0.56, 0.67]	
Peak vertical height (cm)	*Positions*		< 0.001
	Flat (0°DF)	-	
	Incline (10°DF)	4.96 [3.16, 7.81]	
	Step (FFS)	0.45 [0.29, 0.72]	
Total positive work (J)	*Positions*		< 0.001
	Flat (0°)	-	
	Incline (10°DF)	0.88 [0.81, 0.97]	
	Step (FFS)	0.62 [0.57, 0.82]	
	Gender		< 0.001
	Male	-	
	Female	0.68 [0.57, 0.82]	

Notes. Reference indicated with hyphen (-). Only significant predictors of CRT outcomes are reported, with the predictors of gender, BMI, physical activity levels, and age removed during stepwise regression when not significant.
*Estimates represent rate ratios, where rate ratios lower than 1.00 indicate lower outcome values when compared to the reference condition. 95 % *CI* and *P* values adjusted using multivariate *t*-test distribution.
Abbreviations. BMI = body mass index; *CI* = confidence interval; CRT = calf raise test; DF = dorsiflexion. FFS, forefoot supported.

Table 4
Mixed-effects models post-hoc comparisons for the foot starting position.

CRT outcomes	Variables (Comparison / Reference)	Estimates* [95 % *CI*]	*P*-value
Repetitions (*n*)	*Positions*		
	Incline (10°DF) / Flat (0°DF)	0.77 [0.69, 0.85]	< 0.001
	Step (FFS) / Flat (0°DF)	0.61 [0.55, 0.69]	< 0.001
	Step (FFS) / Incline (10°DF)	0.80 [0.72, 0.90]	< 0.001
Total vertical displacement (cm)	*Positions*		
	Incline (10°DF) / Flat (0°DF)	0.88 [0.79, 0.98]	0.014
	Step (FFS) / Flat (0°DF)	0.61 [0.55, 0.68]	< 0.001
	Step (FFS) / Incline (10°DF)	0.70 [0.63, 0.77]	< 0.001
Peak vertical height (cm)	*Positions*		
	Incline (10°DF) / Flat (0°DF)	1.18 [1.10, 1.26]	< 0.001
	Step (FFS) / Flat (0°DF)	0.90 [0.84, 0.97]	0.002
	Step (FFS) / Incline (10°DF)	0.77 [0.72, 0.82]	< 0.001
Total positive work (J)	*Positions*		
	Incline (10°DF) / Flat (0°DF)	0.88 [0.79, 0.99]	0.023
	Step (FFS) / Flat (0°DF)	0.62 [0.56, 0.69]	< 0.001
	Step (FFS) / Incline (10°DF)	0.70 [0.63, 0.78]	< 0.001

Notes. *Estimates represent rate ratios, where rate ratios lower than 1.00 indicate lower outcome values when compared to the reference condition. 95 % *CI* and *P* values adjusted using multivariate *t*-test distribution.
Abbreviations. *CI* = confidence interval; CRT = calf raise test; DF = dorsiflexion. FFS = forefoot supported.

The foot starting position is one of many CRT parameters identified as variable in research and clinical settings, with the flat (0° dorsiflexion) foot position being the most common, followed by the incline (10° dorsiflexion) position [3]. Although these foot starting positions are common, no previous study has directly compared CRT outcomes between positions. Our results support that changing foot starting position significantly influences CRT outcomes, which might partly explain the variable normative values reported in the literature with regards to repetitions [17] given the lack of use of a standardised protocol [3]. Indeed, performing the CRT from flat (0° dorsiflexion) [1,16] and incline (10° dorsiflexion) [15] positions have both been used to establish normative values, where the incline position may be considered more functional than flat due to its greater range of motion. Overall, our results indicate that performing the CRT on the flat will yield a superior number of repetitions, with 23 % and 39 % more repetitions compared to on a 10° incline or with the forefoot on the edge of a step, respectively. These differences should be considered when administering the CRT, contrasting clinical outcomes to normative values, and comparing literature using different protocols.

We also found that foot starting position influenced other CRT outcomes (i.e., peak vertical height, total vertical displacement, and total positive work), which were measured using a valid and reliable iOS mobile application [29]. Although the primary outcome evaluated in clinics is repetitions, Svantesson, Osterberg, Thomeé , and Grimby [32] suggested to also assess peak height since lower heights could lead to a greater number of repetitions as less work is required per repetition. Additionally, from a clinical perspective, it is noteworthy that the number of repetitions and peak height CRT outcomes are associated with different physiological and structural factors [33]. Contractile tissue and muscle endurance metabolism determine the number of repetitions [34], while tendon length moreover determines peak height [35]. These TS muscle-tendon unit properties together influence the total vertical displacement and work performed [2,32].

Furthermore, research supports that peak height and work are more sensitive outcomes than repetitions in presence of pathology and functional deficits [33,35,36]. Overall, our study indicates that performing the CRT on the flat yields a superior total vertical displacement and positive work, with 12 % and 38–39 % greater values than from a 10° incline or with the forefoot on the edge of a step, respectively. Peak vertical height, however, was greatest on the 10° incline, being 18 % and 15 % greater than from flat or step conditions. Again, these discrepancies in outcomes highlight how test protocol can affect outcomes, which warrant clinical and research consideration.

Repetitions, total vertical displacement, and total work were the greatest in the plantigrade (flat) foot starting position, and the lowest from the step. Although our study did not measure muscle fibre length using ultrasound, ankle torque using inverse dynamics, or muscle activity using electromyography (EMG), changes in ankle position have been shown to affect muscle length, torque values, and EMG [21] due to the length-tension relationship [21,37]. Sale, Quinlan, Marsh, McComas, and Belanger [21] reported that increasing ankle dorsiflexion lengthens the TS muscles and increases plantarflexion torque, which could presumably increase the number of repetitions, total vertical displacement, and total work outcomes from the CRT performed on an incline or step compared to flat. However, increasing ankle range of motion during plantarflexion efforts also increases the contraction time and EMG activation of the TS muscles [21], thus potentially leading to an earlier onset of muscle fatigue and CRT termination. An inclined surface and a step require greater ranges of motion and stabilisation throughout that range than from flat, with greater work demands [38] and TS activation [39], and potentially greater functional relevance. The ankle joint moments [40] and vertical mechanical loads are also greater for incline and step than flat variants. When completing repetitive calf raises, the intrinsic and extrinsic foot muscles are required to support the foot and generate the midfoot and ankle joint moments needed to perform the calf raise motion [40,41]. As the CRT was executed to the same pace across foot starting positions, the time during which the heel was in contact with a supporting surface between repetitions was speculatively greatest in the flat variant, followed by the incline condition. In the step condition, the heel was never in contact with a supporting surface; hence, the muscles were presumably always contracted and the time under tension was greatest, leading to earlier muscle fatigue and lesser repetitions and positive work. All these factors point to quicker muscle fatigue in the incline and step conditions, resulting in lower CRT outcomes in comparison to the flat condition.

Presumably, peak height should have been greatest in the step condition due to an increased range of ankle motion, which was not the case. This finding is likely due to participants not starting in full dorsiflexion range of motion in the step (forefoot supported) condition despite instructions. As the CR_{app} takes the marker position in the first video frame as defining a vertical position of zero, the 10° incline condition often resulted in a greater range of calf raise motion and peak height than the step condition as the ankle was visibly in greater dorsiflexion. Furthermore, participants had a tactile end point to return to in the incline condition compared to the step condition, encouraging them to return to a dorsiflexed position. Therefore, for repeatable and

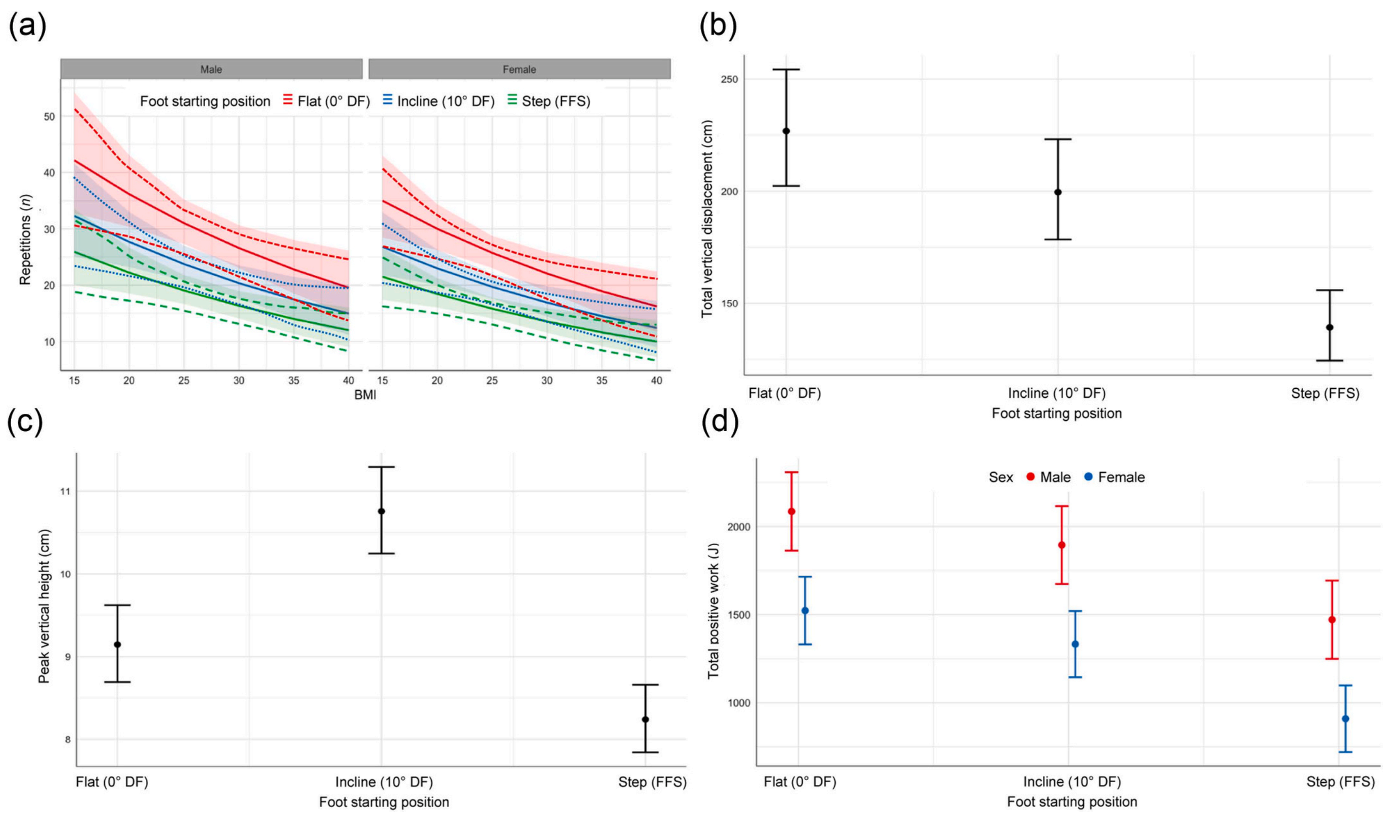

Fig. 2. Figures illustrating the effects of the three foot starting positions on calf raise test outcomes. A. Number of repetitions, B. Total vertical displacement, C. Peak vertical height, and D. Total positive work. Data are presented as linear graphs or dot plots with mean and standard deviation values. *Abbreviations.* BMI = body mass index. DF = dorsiflexion. FFS = forefoot supported.

functional assessment, the incline condition can be recommended. Range of motion during testing was not actively monitored as part of this investigation, which could have confirmed these observations.

Females performed fewer repetitions than males (17 %). This gender difference aligns with previous studies [16] and general physiology, wherein females exhibit lower strength levels, cross-sectional area of the TS muscles, and plantarflexor torque than males [16,42–44]. However, some studies[45,46] found no gender-specific differences in repetitions performed during the CRT. It is debatable whether the 17 % difference (three to five repetition) we found is clinically meaningful given that six repetitions typically defines the minimal detectable change based on test-retest data [15]. In agreement with a prior study [18], we also found that BMI affected the number of repetitions, wherein a one unit increase in BMI resulted in a 3 % decrease in repetition. Individuals with an increased BMI are at a biomechanical disadvantage during the CRT due to the need to support additional body mass against gravity, which may lead to earlier TS muscle fatigue. These findings align with research indicating poorer musculoskeletal [47], fitness [48], and muscular endurance [49] outcomes in individuals with greater BMI. However, BMI did not affect the total work metric likely due to body mass being accounted for in the work computations.

In contrast to prior studies finding age and physical activity levels influencing CRT repetitions [15,16,45], these predictors did not influence any of the CRT outcomes in our population. Our population had a relatively narrow age range and were all engaged in moderate-to-high levels of physical activity based on the short form IPAQ; hence, this homogeneity would have reduced data variability and potentially affected our results. This homogeneous nature of our population may limit the generalisability of our findings to a broader population. As accounting for the potential influence of predictors on CRT outcomes was secondary to examining the effect of foot starting position, we did not specifically design the study to examine the effects of predictors on CRT outcomes, but rather incorporated them as covariates.

Our study has limitations. First, the findings are based on a sample of healthy young adults, which limits their generalisability to clinical populations and across age groups. Future research examining the effects of foot position in pathological conditions and broader populations is warranted to promote evidence-based practice using this assessment tool. Nevertheless, this study provides a starting point for further research into the effects of foot starting position on CRT outcomes, with implications for individuals with weakness of the plantarflexors. Further, the step condition was meant to involve full dorsiflexion range, with participants not reaching full dorsiflexion based on our video observations. We did not standardise or quantify each participant's full range of motion or monitor range of motion during testing. Hence, we cannot define precisely how much dorsiflexion affects CRT performance. Finally, we can only make inferences to muscle activity, fatigue levels, and muscle fibre length as EMG and ultrasound were not used.

5. Conclusions

Significant differences between the three most common foot starting positions of the CRT were found in the number of repetitions, peak vertical height, total vertical displacement, and total positive work. Interpretation of CRT outcomes and between-study comparisons need to consider foot position. Among the predictors, gender and BMI significantly influence the number of repetitions and total positive work, whereas age and physical activity levels did not influence any of the CRT outcomes. The latter result might have stemmed from the homogeneity of participants. To provide evidence-based practice in terms of clinical decision-making, future research is recommended to examine the effects of varying CRT foot starting positions in pathological and other populations, such as paediatric and elderly.

Brief summary

What is already known.

- The calf raise test is used to assess triceps surae muscle function in clinic and research.
- The test involves performing repeated concentric and eccentric plantarflexion contractions in unilateral stance until fatigue (i.e., volitional cessation).
- There is no consensus protocol used to administer the calf raise test despite its common use, which may influence test outcomes and interpretation.

What this study adds.

- Varying the foot starting position (flat, 10° incline, step) significantly affected calf raise test outcomes.
- Repetitions, peak height, total displacement, and total work were greater when the foot started from flat than a 10° incline or step.
- Repetitions were higher in males and individuals with lower body mass index, as was total work in males.

Ethics approval

The Human Research Ethics Committee of the University of Waikato granted ethical approved to conduct this randomised crossover study with repeated measures study (HREC2020#11), which followed the Declaration of Helsinki.

Funding

No funding was sought or received to undertake this work.

CRediT authorship contribution statement

Masayoshi Kubo: Writing – review & editing, Methodology, Conceptualization. **Josie Athens:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation, Conceptualization. **Seth O'Neill:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Ma. Roxanne Fernandez:** Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kim Hébert-Losier:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Data statement

To foster transparency and support reproducibility, data have been made openly available in the Open Science Framework at https://doi.org/10.17605/OSF.IO/G2PUK [50].

Declaration of Competing Interest

One of the authors (KHL) is one of the developers of the free-to-use Calf Raise application. The data for this study were obtained from independent researchers (RF, SO, IH) not related to the development of the Calf Raise application.

Acknowledgements

The authors would like to thank Ivana Hanzlíková (IH) and Sana Oladi (SO) for their assistance during data collection. The authors also thank all participants for volunteering to participate.

References

[1] Lunsford BR, Perry J. The standing heel-rise test for ankle plantar flexion: criterion for normal. Phys Ther 1995;75(8):694–8. https://doi.org/10.1093/ptj/75.8.694.
[2] Silbernagel KG, Nilsson-Helander K, Thomee R, Eriksson BI, Karlsson J. A new measurement of heel-rise endurance with the ability to detect functional deficits in patients with Achilles tendon rupture. Knee Surg Sports Trauma Arthrosc 2010;18 (2):258–64. https://doi.org/10.1007/s00167-009-0889-7.
[3] Hébert-Losier K, Newsham-West RJ, Schneiders AG, Sullivan SJ. Raising the standards of the calf-raise test: a systematic review. J Sci Med Sport 2009;12(6): 594–602. https://doi.org/10.1016/j.jsams.2008.12.628.
[4] Maurer C, Finley A, Martel J, Ulewicz C, Larson CA. Ankle plantarflexor strength and endurance in 7-9 year old children as measured by the standing single leg heel-rise test. Phys Occup Ther Pedia 2007;27(3):37–54.
[5] André H-I, Carnide F, Borja E, Ramalho F, Santos-Rocha R, Veloso AP. Calf-raise senior: a new test for assessment of plantar flexor muscle strength in older adults: protocol, validity, and reliability. Clin Inter Aging 2016;11:1661–74. https://doi.org/10.2147/CIA.S115304.
[6] Lee JH, Jung HW, Jung TS, Jang WY. Reliability and usefulness of the single leg heel raise balance test in patients with chronic ankle instability. Sci Rep 2021;11 (1):20369. https://doi.org/10.1038/s41598-021-99466-8.
[7] Svantesson U, Osterberg U, Grimby G, Sunnerhagen KS. The standing heel-rise test in patients with upper motor neuron lesion due to stroke. Scand J Rehabil Med 1998;30(2):73–80.
[8] Monteiro DP, Britto RR, Lages AC, et al. Heel-rise test in the assessment of individuals with peripheral arterial occlusive disease. Vasc Health Risk Manag 2013;9:29–35. https://doi.org/10.2147/vhrm.S39860.
[9] Byrne C, Keene DJ, Lamb SE, Willett K. Intrarater reliability and agreement of linear encoder derived heel-rise endurance test outcome measures in healthy adults. J Electro Kinesiol 2017;36:34–9. https://doi.org/10.1016/j.jelekin.2017.07.004.
[10] Olsson N, Petzold M, Brorsson A, Karlsson J, Eriksson BI, Silbernagel KG. Predictors of clinical outcome after acute Achilles tendon ruptures. Am J Sports Med 2014;42 (6):1448–55. https://doi.org/10.1177/0363546514527409.
[11] De la Fuente C, Peña y Lillo R, Carreño G, Marambio H. Prospective randomized clinical trial of aggressive rehabilitation after acute Achilles tendon ruptures repaired with Dresden technique. Foot (Edinb) 2016;26:15–22. https://doi.org/10.1016/j.foot.2015.10.003.
[12] Nilsson L, Thorlund JB, Kjær IL, Kazlauskas A, Christensen M. Long-term follow-up after acute achilles tendon rupture — does treatment strategy influence functional outcomes? Foot (Edinb) 2021;47:101769. https://doi.org/10.1016/j.foot.2020.101769.
[13] Keklicek H, Selcuk H, Yilmaz A. Fatigue of the intrinsic foot core muscles had a greater effect on gait than extrinsic foot core muscles: a time-series based analyze. Foot (Edinb) 2024;59:102088. https://doi.org/10.1016/j.foot.2024.102088.
[14] Ganderton C, Henry M, Walker A, McGinley P, Verhagen E. Implementation of calf endurance training in a touring group of professional circus performers: a feasibility study. Med Probl Perform Art 2021;36(1):54–60. https://doi.org/10.21091/mppa.2021.1008.
[15] Hébert-Losier K, Wessman C, Alricsson M, Svantesson U. Updated reliability and normative values for the standing heel-rise test in healthy adults. Physiotherapy 2017;103(4):446–52. https://doi.org/10.1016/j.physio.2017.03.002.
[16] Jan M-H, Chai H-M, Lin Y-F, et al. Effects of age and sex on the results of an ankle plantar-flexor manual muscle test. Phys Ther 2005;85(10):1078–84. https://doi.org/10.1093/ptj/85.10.1078.
[17] Bohannon RW. The heel-raise test for ankle plantarflexor strength: a scoping review and meta-analysis of studies providing norms. J Phys Ther Sci 2022;34(7): 528–31. https://doi.org/10.1589/jpts.34.528.
[18] Hébert-Losier K, Ngawhika TM, Gill N, Balsalobre-Fernandez C. Validity, reliability, and normative data on calf muscle function in rugby union players from the Calf Raise application. Sports Biomech 2022:1–22. https://doi.org/10.1080/14763141.2022.2118158.
[19] Maganaris CN. Force-length characteristics of the in vivo human gastrocnemius muscle. Clin Anat 2003;16(3):215–23. https://doi.org/10.1002/ca.10064.
[20] Hali K, Zero AM, Rice CL. Effect of ankle joint position on triceps surae contractile properties and motor unit discharge rates. Physiol Rep 2021;8(24):e14680. https://doi.org/10.14814/phy2.14680.
[21] Sale D, Quinlan J, Marsh E, McComas AJ, Belanger AY. Influence of joint position on ankle plantarflexion in humans. J Appl Physiol Respir Environ Exerc Physiol 1982;52(6):1636–42. https://doi.org/10.1152/jappl.1982.52.6.1636.
[22] Enoka RM. Neuromechanics of Human Movement: Third edition. Champaign, IL: Human Kinetics,; 2002.
[23] Monteiro DP, Britto RR, Fregonezi GADF, Dias FAL, Silva MGD, Pereira DAG. Reference values for the bilateral heel-rise test. Braz J Phys Ther 2017;21(5): 344–9. https://doi.org/10.1016/j.bjpt.2017.06.002.

[24] Mishra R, Aranha VP, Samuel AJ. Reliability and reference norms of single heel-rise test among children: a cross-sectional Study. J Foot Ankle Surg 2022. https://doi.org/10.1053/j.jfas.2022.10.007.
[25] Lee PH, Macfarlane DJ, Lam TH, Stewart SM. Validity of the international physical activity questionnaire short form (IPAQ-SF): a systematic review. Int J Behav Nutr Phys Act 2011;8(1):115. https://doi.org/10.1186/1479-5868-8-115.
[26] Dwan K, Li T, Altman DG, Elbourne D. CONSORT 2010 statement: extension to randomised crossover trials. BMJ 2019;366:l4378. https://doi.org/10.1136/bmj.l4378.
[27] van Melick N, Meddeler BM, Hoogeboom TJ, Nijhuis-van der Sanden MWG, van Cingel REH. How to determine leg dominance: the agreement between self-reported and observed performance in healthy adults. PLoS One 2017;12(12):e0189876. https://doi.org/10.1371/journal.pone.0189876.
[28] Hébert-Losier K., Balsalobre-Fernández C. Calf raise mobile application software. 2020. https://doi.org/10.17605/OSF.IO/N9SG7.
[29] Fernandez MR, Athens J, Balsalobre-Fernandez C, Kubo M, Hébert-Losier K. Concurrent validity and reliability of a mobile iOS application used to assess calf raise test kinematics. Musculoskelet Sci Pr 2023;63:102711. https://doi.org/10.1016/j.msksp.2022.102711.
[30] *R: A Language and Environment for Statistical Computing [computer program]*. Version 4.1.1 (2021–08-10)2021.
[31] Douglas Bates MM, Ben Bolker, Steve Walker. Fitting linear mixed-effects models using lme4. J Stat Softw 2015;67(1):1–48. https://doi.org/10.18637/jss.v067.i01.
[32] Svantesson U, Osterberg U, Thomeé R, Grimby G. Muscle fatigue in a standing heel-rise test. Scand J Rehabil Med 1998;30(2):67–72.
[33] Svensson R, Couppe C, Agergaard A, et al. Persistent functional loss following ruptured Achilles tendon is associated with reduced gastrocnemius muscle fascicle length, elongated gastrocnemius and soleus tendon, and reduced muscle cross-sectional area. Transl Sports Med 2019;(6):316–24. https://doi.org/10.1002/tsm2.103.
[34] Holloszy JO. Biochemical adaptations in muscle. Effects of exercise on mitochondrial oxygen uptake and respiratory enzyme activity in skeletal muscle. J Biol Chem 1967;242(9):2278–82.
[35] Baxter JR, Hast DC, Hast MW. Plantarflexor fiber length and tendon slack length are the strongest determinates of simulated single-leg heel raise function. J Biomech 2018:415679. https://doi.org/10.1101/415679.
[36] Zellers JA, Pohlig RT, Cortes DH, Silbernagel KG. Achilles tendon cross-sectional area at 12 weeks post-rupture relates to 1-year heel-rise height. Knee Surg Sports Trauma Arthrosc 2020;28(1):245–52. https://doi.org/10.1007/s00167-019-05608-x.
[37] Cresswell AG, Löscher WN, Thorstensson A. Influence of gastrocnemius muscle length on triceps surae torque development and electromyographic activity in man. Exp Brain Res 1995;105(2):283–90. https://doi.org/10.1007/BF00240964.
[38] McIntosh AS, Beatty KT, Dwan LN, Vickers DR. Gait dynamics on an inclined walkway. J Biomech 2006;39(13):2491–502. https://doi.org/10.1016/j.jbiomech.2005.07.025.
[39] Lichtwark GA, Wilson AM. Interactions between the human gastrocnemius muscle and the Achilles tendon during incline, level and decline locomotion. J Exp Biol 2006;209(21):4379–88. https://doi.org/10.1242/jeb.02434.
[40] Chiu LZF, Dæhlin TE. Midfoot and ankle mechanics in block and incline heel raise exercises. J Strength Cond Res 2021;35(12):3308–14. https://doi.org/10.1519/jsc.0000000000004145.
[41] Akuzawa H, Imai A, Iizuka S, Matsunaga N, Kaneoka K. The influence of foot position on lower leg muscle activity during a heel raise exercise measured with fine-wire and surface EMG. Phys Ther Sport 2017;28:23–8. https://doi.org/10.1016/j.ptsp.2017.08.077.
[42] Ema R, Kawaguchi E, Suzuki M, Akagi R. Plantar flexor strength at different knee positions in older and young males and females. Exp Gerontol 2020;142:111148. https://doi.org/10.1016/j.exger.2020.111148.
[43] Sepic SB, Murray MP, Mollinger LA, Spurr GB, Gardner GM. Strength and range of motion in the ankle in two age groups of men and women. Am J Phys Med 1986;65(2):75–84.
[44] Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. Endocr Rev 2018;39(5):803–29. https://doi.org/10.1210/er.2018-00020.
[45] Sara L, Gutsch S, Hunter S. The single-leg heel raise does not predict maximal plantar flexion strength in healthy males and females. PLoS One 2021;16(8):e0253276. https://doi.org/10.1371/journal.pone.0253276.
[46] Sman AD, Hiller CE, Imer A, Ocsing A, Burns J, Refshauge KM. Design and reliability of a novel heel rise test measuring device for plantarflexion endurance. Biomed Res Int 2014;2014:391646. https://doi.org/10.1155/2014/391646.
[47] Jiang L, Tian W, Wang Y, et al. Body mass index and susceptibility to knee osteoarthritis: a systematic review and meta-analysis. Jt Bone Spine 2012;79(3):291–7. https://doi.org/10.1016/j.jbspin.2011.05.015.
[48] Joshi P, Bryan C, Howat H. Relationship of body mass index and fitness levels among schoolchildren. J Strength Cond Res 2012;26(4). https://doi.org/10.1519/JSC.0b013e31822dd3ac.
[49] Mayer JM, Nuzzo JL, Chen R, et al. The impact of obesity on back and core muscular endurance in firefighters. J Obes 2012;2012:729283. https://doi.org/10.1155/2012/729283.
[50] Hébert-Losier K. Calf raise test foot position dataset. Open Sci Framew 2024. https://doi.org/10.17605/OSF.IO/G2PUK.