

Reliability and Asymmetry Associated with Different Plantar Flexion Assessments Using a Portable Fixed Dynamometer

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Abstract

Background

Decreased plantar flexion strength has been linked to several lower limb injuries such as ankle sprains, Achilles tendon ruptures and calf muscle strains. Therefore, it would seem important to assess and monitor an individual's plantar flexion strength.

Aims

The purpose of this study was to, 1) quantify the intra- and inter-session reliability of a portable fixed dynamometer (PFD) for measuring peak force (PF) and peak RFD (PRFD) during two dynamic plantar flexion assessments, and 2) determine the inter-limb and inter-protocol asymmetries for PF and PRFD.

Methods

Eleven participants completed both neutral and maximal dorsi-flexed movements over three testing sessions separated by seven days.

Results

Good to excellent relative consistency (intraclass correlation coefficients – ICC) and acceptable absolute intra- and inter-session reliability (coefficient of variation – CV) was observed for PF during both protocols (ICC = 0.90–0.99, CV = 1.6–5.3%). Poor to moderate intra- and inter-session reliability was observed for PRFD measures during both protocols (ICC = 0.48–0.96, CV = 5.7–27.0%). There were no differences between left and right legs except for PRFD for the neutral position ($p < 0.05$, ES = -0.82). There were significant differences between protocols, with the neutral position producing higher force outputs ($p < 0.01$, 6.44–66.22%, ES = 1.05–1.75).

Conclusions

It appears that PFD can be used to reliably measure PF during two dynamic plantar flexion protocols in a healthy male population, however the results from the different protocols cannot be used inter-changeably.

1.0 Introduction

The ankle joint and its associated musculature are pivotal in a range of activities and athletic movements. This research specifically focuses on the plantar flexors, which have garnered significant attention due to their essential role in human locomotion, as well as in running and jumping [1–3]. Decreased plantar flexion strength has been linked to many lower limb injuries such as ankle sprains [4], Achilles tendon ruptures and disorders [5] and calf muscle strains [6]. Given the significance of plantar flexion strength for rehabilitation and performance outcomes, it is crucial to track and monitor an individual's plantar flexion strength. Essential to this process is the accurate and reliable recording of data, which is the primary focus of this article.

Plantar flexion tests are commonly performed either standing or seated. The triceps surae muscle is the main plantar flexor and consists of the lateral gastrocnemius (LG), medial gastrocnemius (MG) and soleus muscle. The LG and MG

are biarticular muscles crossing both the ankle and knee joint, while the soleus is a uniarticular muscle crossing only the ankle joint. During plantar flexion, the medial gastrocnemius is more active at a 180° knee angle (standing), while the soleus can be targeted more effectively at a 90° knee angle (seated) [7, 8]. The focus of this article is standing plantar flexion.

In a clinical setting, plantar flexion strength is commonly tested via isokinetic muscle testing devices [9], force plates [10], handheld dynamometers [11], and manual muscle testing. Most researchers have utilized an isokinetic dynamometer [9, 12–14], however these have several limitations due to cost, size and portability. Additionally, these machines require specialist training with regular use.

In recent years, the use of portable commercially available force plates has become a lot more common in strength and conditioning and clinical settings [10, 15]. Force plates overcome many of the limitations associated with isokinetic dynamometers, however, still have a relatively large cost, which is a primary limitation for many practitioners. Force plates with a sampling frequency of 1000 Hz has been reported to reliably test plantar flexor isometric strength in a standing position (ICC = 0.98–0.99, CV = 3.0–3.3%) with bilateral and unilateral variations [16]. The only variable of interest measured was peak force (PF). Conversely, handheld dynamometers are inexpensive, small and portable, yet lack validity and are likely influenced by the strength of the examiner [11]. Additionally, most handheld dynamometers only produce a peak force output. Though this equipment has low concurrent validity, it has been shown to be reliable, especially in a fixed position (ICC = 0.96–0.96) [17].

Portable fixed dynamometry (PFD) overcomes all aforementioned limitations experienced with isokinetic dynamometry force plates and handheld dynamometers; however, the reliability of such technology has not been established during a standing plantar flexor test. Furthermore, the majority of researchers that have determined the reliability of these devices have focused on isometric assessments, however the authors propose that a PFD dynamic standing plantar flexion test could be more appropriate for athletes and those in late-stage rehab/return to play programs. This research focuses on two dynamic plantar flexor assessments beginning from a neutral position and dorsi-flexed position. The aim of this study was firstly, to quantify both intra- and inter-session reliability of PFD for measuring different force-time variables and secondly, determine inter-limb and inter-protocol asymmetries for different force-time variables during two dynamic plantar flexion tests.

2.0 Methodology

2.1 Experimental approach to the problem

A cross-sectional, repeated measures design was used for comparative analysis of reliability for peak force and rate of force development (RFD) during two different dynamic plantar flexion assessments, measured with PFD (Hawkins TruStrength, Portland, Maine). The two protocols were performed standing beginning in either a neutral (see Fig. 1A) or maximal dorsi-flexed position (see Fig. 1B). Participants attended a familiarization session and three testing sessions exactly seven days apart at the same time of day. Reliability was established using change in the mean, intraclass correlation coefficients (ICCs) and coefficient of variation (CVs).

2.2 Participants

11 recreationally resistance trained males (age, 22.64 ± 2.69 y; body mass, 88.34 ± 13.98 kg; height, 181.27 ± 7.34 cm; resistance training experience, 6.6 ± 4.65 y) volunteered to participate in this study. Sporting background for the participants included nine recreational athletes of various sports including cricket, tennis, football, and one semi-professional basketball, and one semi-professional touch rugby player. All 11 participants were fully informed of the risk

involved and gave written informed consent. This research was approved by the University's Ethic Committee (Ethics 23/175).

2.3. Procedures

Participants performed a 10-minute standardized warm-up, consisting of 5-minutes of jogging on a treadmill at a self-selected pace, followed by two submaximal trials at 50% and 75% effort, each leg. The PFD was attached to a base plate, with the opposite side having a compression pad attached (as shown in Fig. 1). The base plate was placed near the wall, the exact distance determined by each participant, as they were asked to position themselves with their elbows at 90°, with forearms resting on the wall, to keep balance. The participant placed one foot on the compression pad, ensuring the ball of the foot was in the centre of the pad. The opposite foot was hovering slightly above the base plate. The participant was asked to plantar flex and find their top position (maximal plantar flexion). After the participant had completed their warm-up trials, they completed five maximal effort trials on each leg, for each protocol (neutral and dorsi-flexed). The tester set the pre-tension (participants body weight) before counting down the participant "3,2,1 Up!" and getting them to hold for 3 seconds at the top. The participants were instructed to push up as hard and as fast as possible. If participants did any compensatory movements such as using their upper limbs or performing a countermovement, then a retrial was given. Two minutes of rest was given between each trial.

2.3.1 Equipment

The PFD used, was a wireless load cell that measured force at 1200 Hz. The device was attached to a base plate, placed on the ground. A flat compression pad was placed on the top side of the device. The PFD device was zeroed in between each trial to account for any drift. Everyone's force onset and offset was established when the individuals pre-tension threshold was broken.

2.4 Data Analyses

Data from each trial was exported via a mobile application (Hawkins TruStrength, Portland, Maine). The application automatically calculated each variable of interest, which were calculated in the period between the force onset and offset, otherwise known as the contraction duration. Peak force was calculated as the absolute maximum force whilst peak RFD was calculated using an 8-tap FIR filter. This filter removed some noise, without distorting the true peak and is essentially a rolling average of eight datapoints to find the peak RFD in the signal, during the contraction duration. A steady pre-tension period prior to the force onset was observed for all trials. After each session, the data was exported from the HTS mobile application into an excel spreadsheet.

2.5 Statistical Analysis

All statistical analysis were performed using IBM SPSS statistical software package (version 29.0; IBM Corporation, New York, USA). Outlier and normality analysis were performed on the raw data. Normality was determined using Shapiro Wilk test. Any extreme outliers were removed before further analysis occurred. The best three trials were used for analysis and data was reported as mean and standard deviations for each variable of interest. Absolute and relative consistency were used to quantify reliability and systematic biases were determined using a repeated measures ANOVA with Bonferroni post hoc comparisons. Absolute consistency between trials and sessions were quantified using CV's, where measures less than or equal to 10% were deemed acceptable [18]. Relative consistency between trials and sessions was determined using an ICC, and classified as follows: 'very poor' (< 0.20), 'poor' (0.20–0.49), 'moderate' (0.50–0.74), 'good' (0.75–0.90) or 'excellent' (> 0.90) [19]. Differences between left and right legs were determined using paired T-tests and hedges g effect sizes (ES). Effect sizes were interpreted using the following criteria: trivial effect = ≤ 0.2 , small effect = 0.21–0.49, medium effect = 0.5–0.79, large effect = ≥ 0.80 [20].

Table 1
Intra-session reliability of neutral and dorsi-flexed plantar flexion assessment

Variable	Mean ± SD			% Change in mean	CV		ICC			
	Trial 1	Trial 2	Trial 3	(95% CI)		(95% CI)		(95% CI)		
				Trial 2 – 1	Trial 3 – 2	Trial 2 – 1	Trial 3 – 2	Trial 2 – 1	Trial 3-2	
Neutral position										
Peak force left (N)	1113.6 ± 142.3	1079.4 ± 127.9	1104.9 ± 143.4	-3.0 (-5.5 - -0.3)	2.3 (0.4–4.2)	3.3 (2.4–5.5)	2.3 (1.7–3.8)	0.95 (0.84–0.98)	0.97 (0.92–0.99)	
Peak force right (N)	1112.9 ± 142.2	1105.4 ± 137.3	1101.0 ± 138.2	-0.6 (-2.8–1.6)	-0.4 (-2.1–1.3)	2.7 (2.0–4.5)	2.1 (1.6–3.5)	0.97 (0.89–0.99)	0.98 (0.93–0.99)	
Peak RFD left (N·s-1)	3506.7 ± 762.5	3126.3 ± 597.6	3239.6 ± 594.2	-10.6 (-16.4 - -4.5)	7.7 (2.6–13.0)	8.5 (6.1–14.3)	5.7 (4.0–9.9)	0.87 (0.63–0.96)	0.94 (0.81–0.98)	
Peak RFD right (N·s-1)	3847.1 ± 845.9	3750.3 ± 1186.8	3732.4 ± 1138.1	-6.6 (-19.9–9.0)	0.9 (-9.2–12.2)	20.7 (14.7–36.3)	13.7 (9.8–23.6)	0.75 (0.38–0.92)	0.92 (0.77–0.97)	
Dorsi-flexed position										
Peak force left (N)	1038.4 ± 135.5	1038.8 ± 153.9	1030.5 ± 138.9	-0.2 (-2.0–1.7)	-0.6 (-2.0–0.8)	2.3 (1.7–3.8)	1.8 (1.3–2.9)	0.98 (0.94–0.99)	0.99 (0.97–1.00)	
Peak force right (N)		1033.6 ± 136.1	1026.2 ± 136.8	1016.8 ± 140.8	-0.7 (-3.0–1.6)	-1.0 (-2.2–0.3)	2.9 (2.1–4.8)	1.6 (1.1–2.6)	0.97 (0.90–0.99)	0.99 (0.97–1.00)
Peak RFD left (N·s-1)	2594.8 ± 692.4	2644.3 ± 776.6	2537.9 ± 763.3	1.3 (-8.0–11.4)	-4.6 (-10.4–1.7)	12.4 (8.9–21.2)	8.1 (5.8–13.6)	0.88 (0.66–0.96)	0.96 (0.87–0.99)	
Peak RFD right (N·s-1)	2528.6 ± 1076.5	2355.9 ± 958.3	2544.8 ± 854.7	-7.2 (-17.4–4.2)	11.1 (0.1–23.2)	15.2 (10.9–26.2)	13.5 (9.7–23.2)	0.93 (0.80–0.98)	0.94 (0.82–0.98)	

3.0 Results

The within-session reliability of the variables of interest for the two protocols can be observed in Table 1. There appeared no systematic change within the variables across the three trials. The largest change was observed between

trials 2 – 1 for peak RFD left leg (-10.6%) for the neutral position and between trials 3 – 2 for peak RFD right leg (11.1%) for the dorsi-flexed position. In terms of absolute consistency, all CVs were less than 10% (2.1–8.5%), except for RFD on the right leg (13.7–20.7%) for the neutral position. With regards to the dorsi-flexed position, peak force CVs were below 10% (1.6–2.9%), while peak RFD on both legs ranged from 8.1–15.2%. With regards to relative consistency, all ICCs were equal to or greater than 0.75 for the neutral position and equal to or greater than 0.88 for the dorsi-flexed position.

The intersession reliability is detailed in Table 2. Once again, there appeared no systematic change within the variables across the three trials. The largest change was observed between trials 3 – 2 for peak RFD left leg (-16.2%) for the neutral position, and between trials 3 – 2 for peak RFD right leg (4.9%) for the dorsi-flexed position. All peak force variables for both testing positions had CVs below 10% (2.8–5.3%), however all peak RFD variables had CVs above 10% (10.8–27.0%). In terms of relative consistency, peak force variables for both testing positions were equal to or above 0.90 (0.90–0.97), while peak RFD ranged from 0.48–0.81.

The inter-limb asymmetries and between protocol differences are presented in Table 3. There were no significant differences between left and right legs, except for peak RFD for the neutral position (ES = -0.82). There was minimal asymmetry between left and right leg for peak force (-1.10–0.57%), however larger asymmetries were observed for peak RFD values (-11.74–8.35%). In terms of protocol differences (neutral versus dorsi-flexed start position), there were significant differences for peak force values ($p < 0.01$, 6.44–8.10%, ES = 1.05–1.75) the neutral position producing higher force outputs. Similarly, there were large significant differences in peak RFD values ($p < 0.01$, 34.91–66.22%, ES = 1.30–1.52).

Table 2
Inter-session reliability

Variable	Mean ± SD			% Change in mean (95% CI)		CV (95% CI)		ICC (95% CI)	
	Session 1	Session 2	Session 3	Session 2 – 1	Session 3 – 2	Session 2 – 1	Session 3 – 2	Session 2 – 1	Session 3 – 2
<i>Neutral position</i>									
Peak force left (N)	1110.6 ± 130.9	1145.2 ± 158.9	1099.3 ± 135.6	2.8 (-0.3–6.1)	-3.8 (-6.1 - -1.5)	3.9 (2.8–6.5)	3.0 (2.1–4.9)	0.93 (0.79–0.98)	0.96 (0.89–0.99)
Peak force right (N)	1123.5 ± 119.4	1134.2 ± 149.0	1106.4 ± 137.7	0.7 (-2.3–3.7)	-2.4 (-4.7–0.0)	3.7 (2.7–6.2)	3.0 (2.1–4.9)	0.93 (0.78–0.98)	0.96 (0.88–0.99)
Peak RFD left (N·s-1)	3807.8 ± 680.2	3982.6 ± 751.0	3343.5 ± 667.8	4.5 (-6.9–17.3)	-16.2 (-22.9 - -8.9)	15.1 (10.8–26.1)	10.8 (7.7–18.3)	0.48 (-0.06–0.80)	0.77 (0.41–0.92)
Peak RFD right (N·s-1)	3778.0 ± 1116.5	3975.4 ± 1301.8	3776.6 ± 998.6	5.4 (-8.3–21.1)	-4.0 (-16.4–10.3)	18.5 (13.2–32.3)	18.4 (13.1–32.1)	0.81 (0.51–0.94)	0.78 (0.44–0.93)
<i>Dorsi-flexed position</i>									
Peak force left (N)	1035.5 ± 151.6	1042.8 ± 157.7	1035.9 ± 142.2	0.6 (-3.6–5.0)	-0.5 (-3.3–2.3)	5.3 (3.9–8.9)	3.5 (2.5–5.8)	0.90 (0.72–0.97)	0.96 (0.87–0.99)
Peak force right (N)	1028.8 ± 141.3	1022.1 ± 134.6	1025.5 ± 136.0	-0.6 (-4.5–3.4)	0.3 (-1.9–2.7)	5.0 (3.6–8.3)	2.8 (2.1–4.7)	0.90 (0.71–0.97)	0.97 (0.90–0.99)
Peak RFD left (N·s-1)	2648.3 ± 778.3	2596.7 ± 776.7	2592.3 ± 714.5	-2.2 (-19.6–18.9)	0.5 (-16.8–21.4)	27.0 (19.0–48.2)	25.9 (18.3–46.1)	0.49 (-0.04–0.81)	0.51 (-0.01–0.82)
Peak RFD right (N·s-1)	2380.5 ± 642.8	2297.8 ± 702.1	2476.4 ± 921.8	-4.8 (-20.9–14.6)	4.9 (-12.0–25.0)	25.4 (17.9–45.0)	23.9 (16.9–42.3)	0.57 (0.06–0.84)	0.76 (0.39–0.92)

Table 3
Inter-limb and inter-protocol differences

Variable	Mean $\pm$ SD		Between leg comparison		Between protocol comparison	
	Left Leg	Right Leg	Asymmetry (%)	ES (95% CI)	Difference (%)	ES (95% CI)
<i>Neutral position</i>						
Peak force	1099.3 $\pm$ 135.6	1106.4 $\pm$ 137.7	0.57	-0.15 (-0.72–0.42)	L: 6.44 R: 8.10	1.05 $\blacklozenge$ (0.30– 1.78) 1.75 $\blacklozenge$ (0.76– 2.72)
Peak RFD	3343.5 $\pm$ 667.8	3776.6 $\pm$ 998.6	8.35	-0.82* (-1.48 - -0.12)	L: 34.91 R: 66.22	1.30 $\blacklozenge$ (0.46– 2.10) 1.52 $\blacklozenge$ (0.61– 2.40)
<i>Dorsi-flexed position</i>						
Peak Force	1035.9 $\pm$ 142.2	1025.5 $\pm$ 136.0	1.10	0.18 (-0.20–0.75)		
Peak RFD	2592.3 $\pm$ 714.5	2476.4 $\pm$ 921.8	11.74	0.23 (-0.35–0.80)		
Key: * significantly different ($p < 0.05$) from left leg, $\blacklozenge$ significantly different ($p < 0.01$) from dorsi-flexed protocol, L = left leg, R = right leg						

4.0 Discussion

In order to gain a full understanding of the reliability of a measure, it has been recommended that systematic change in mean, absolute and relative consistency are all reported [19]. To the authors knowledge, this was the first study to determine the reliability of a PFD device during two dynamic plantar flexion protocols. Previously, researchers have primarily focused on isometric plantar flexion assessments. The main findings of this research were: 1) in terms of intra-session reliability, all peak force variables were found to have acceptable reliability for both testing protocols (change in mean $\leq 3.0\%$, CV $\leq 3.3\%$, ICC > 0.94), while peak RFD development had poor to moderate reliability (change in mean $\leq 11.1\%$, CV $\leq 20.7\%$, ICC > 0.74); 2) with regards to inter-session reliability, once again, peak force variables were found to have acceptable reliability (change in mean $\leq 3.8\%$, CV $\leq 5.3\%$, ICC > 0.89), while peak RFD had poor to moderate reliability (change in mean $\leq 16.2\%$, CV ≤ 27.0 , ICC > 0.47); 3) there appeared no significant differences between left and right for the dorsi-flexed position, however peak RFD for the neutral position was significantly different ($p < 0.05$, 8.35%, ES = -0.82): and, 4) in terms of protocol differences, values were significantly higher for peak force ($p < 0.01$, 6.44–8.10%, ES = 1.05–1.75) and peak RFD ($p < 0.01$, 34.91–66.22%, ES = 1.30–1.52) during the neutral position.

In terms of intra-session reliability, both protocols had acceptable absolute (Neutral: 2.1–3.3%, Dorsi: 1.6–2.9%) and relative consistency (Neutral: 0.95–0.98, Dorsi: 0.97–0.99) for peak force variables. With regards to peak RFD measures, absolute and relative consistency appeared better on the left leg (Neutral: CV = 5.7–8.5%, ICC = 0.87–0.94; Dorsi: CV = 8.1–12.4%, ICC = 0.88–0.96) compared to the right leg (Neutral: CV = 13.7–20.7%, ICC = 0.75–0.92; Dorsi:

CV = 13.5–15.2%, ICC = 0.93–0.94) for both protocols. Force plates have a similar sampling frequency (1000 Hz) to the PFD device used in this study (1200 Hz) and have been reported to have excellent intra-session reliability for single leg standing isometric plantar flexion (CV = 3.2%, ICC = 0.93–0.97) for peak force variables (relative and absolute) [16]. With regards to RFD, there is a paucity of reliability research that has utilized this force-time metric, nonetheless RFD measures have been reported to be typically less reliable than maximum force, especially during the early phase of contraction [21]. With this in mind, further refining of the protocol is required to improve the consistency of this measure.

Similar results were found for between session reliability for peak force during both neutral and dorsi-flexed protocols (CV = 3.0–3.9%, ICC = 0.93–0.96; and CV = 2.8–5.3%, ICC = 0.90–0.97, respectively). Once again, peak RFD was poor to moderate at best for both neutral and dorsi-flexed protocols (CV = 10.8–18.5%, ICC = 0.48–0.81; and CV = 23.9–27.0%, ICC = 0.49–0.76, respectively). As with intra-session reliability, previous research has only focused on peak force metrics. Mattiussi and colleagues [16], reported similar reliability to that of the current study for single leg plantar flexion isometric peak force (CV = 3.0–4.9%, ICC = 0.96–0.98). Given the intra-session results of peak RFD, it is not surprising the poor intersession reliability was observed. Though the authors cannot make direct comparisons to similar protocols, these results are similar to those reported by Juneau and colleagues [22], using similar strain gauge technology during an isometric knee extension (CV = 16.4–24.7%, ICC = 0.50–0.78).

Regarding interlimb asymmetry, there was no significant differences between left and right legs for peak force ($p > 0.05$, 1.10%, ES = 0.18) and peak RFD ($p > 0.05$, 11.74%, ES = 0.23) in the dorsi-flexed position. Similar results were seen for peak force in the neutral position ($p > 0.05$, 0.57%, ES = -0.15), however peak RFD was significantly different between legs, the right leg values greater ($p < 0.05$, 8.35%, ES = -0.82). This finding is likely because all but one participant reported their right leg as their dominant side.

In terms of protocol differences, all metrics were significantly higher in the neutral position, compared to the dorsi-flexed position (PF = $p < 0.01$, 6.44–8.10%, ES = 1.05–1.75 and peak RFD = $p < 0.01$, 34.91–66.22%, ES = 1.30–1.52). This was no surprise, as previous researchers reported on the effects of joint angle on rate of torque development during a prone isometric explosive contraction, reporting higher peak torque and rate of torque development in a neutral position, compared to a dorsi-flexed position, due to a more optimal length tension relationship [23]. These findings highlight the importance of being strict with set up procedures, as small changes in ankle angle can significantly affect the results. Additionally, practitioners may wish to test at shorter muscle lengths during early-stage rehabilitation, and then progressing their athlete/patient to longer muscle lengths during late-stage rehabilitation. Finally, the reader needs to be cognizant that the testing position results are not interchangeable and needs to be wary when comparing plantar flexor results.

5.0 Summary

This study was the first to examine the intra- and inter-session reliability and asymmetry associated with a neutral and dorsi-flexed plantar flexion test, using a novel PFD device. All peak force variables were found to have good to excellent intra- and inter-session reliability in a healthy population, while peak RFD variables were moderate at best. These results are comparable with force plates and other technologies previously used in a variety of different assessments, however this is the first study to report on RFD for the plantar flexors. In terms of asymmetries, for the most part no significant differences were observed between left and right legs for both positions. There were large significant differences between protocols, with significantly higher peak force and peak RFD values in the neutral position, due to the length-tension relationship of the plantar flexors, meaning that the various force measures cannot be used interchangeably.

Declarations

Author Contributions:

Conceptualization, P.H. and J.C.; methodology, P.H. C.R. and D.Y.; software, D.Y.; formal analysis, C.R.; investigation, P.H.; data curation, P.H., C.R.; writing—original draft preparation, C.R.; writing—review and editing, C.R. P.H. and J.C.; visualization, C.R.; supervision, J.C. and C.R.; project administration, D.Y. and C.R. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Competing Interests

John Cronin is a product consultant for Hawkin Dynamics and shareholder in Hawkin TruStrength.

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Ethical Approval and Informed Consent

The present study was approved by the Ethics Committee of Auckland University of Technology (Ethics 23/175). and was conducted in accordance with Declaration of Helsinki. All participants signed informed consent before participating in the study.

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Figures

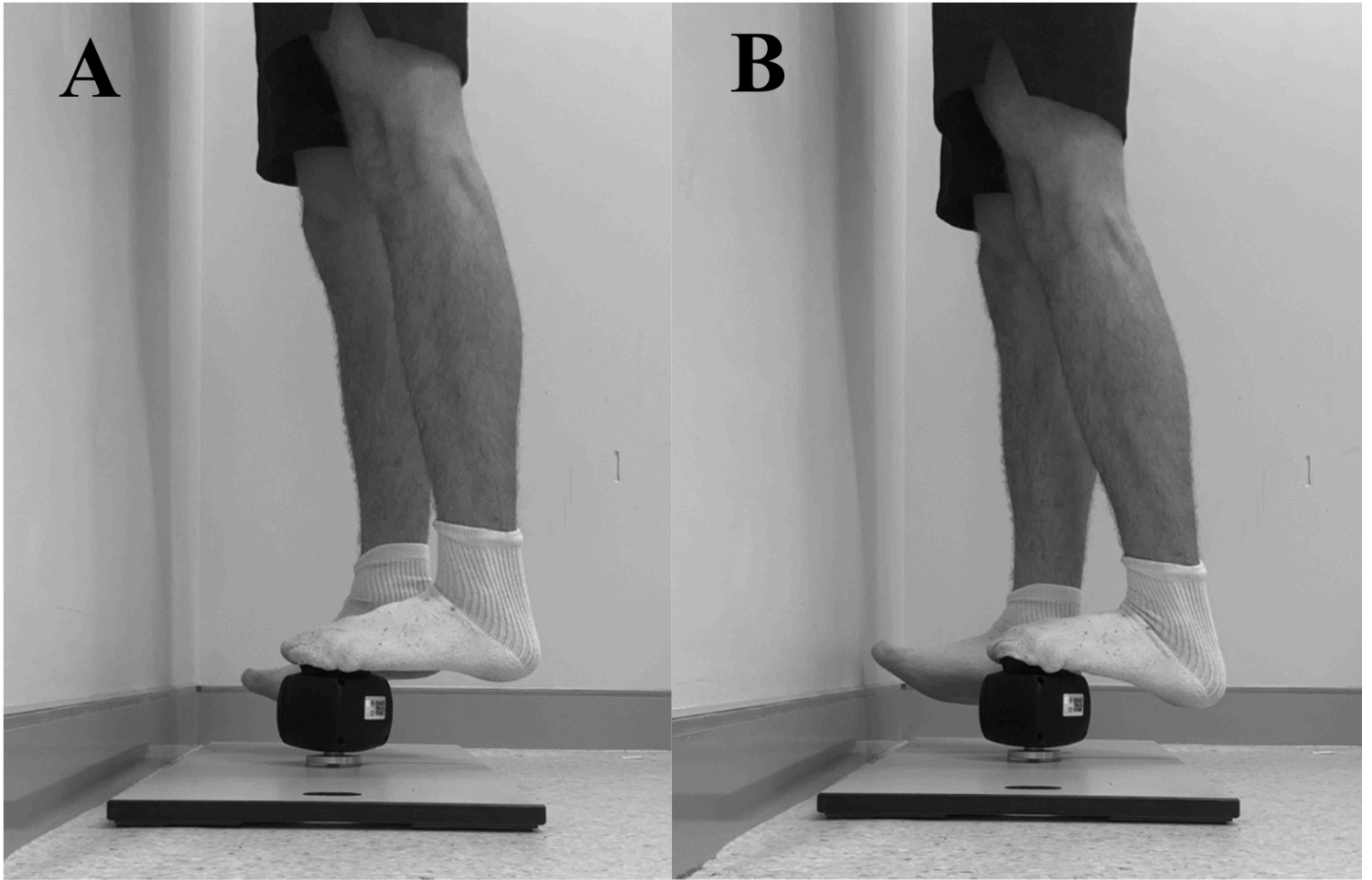


Figure 1

A) Neutral protocol set up, B) Dorsi-flexed protocol set up