Reliability and validity of a low-cost portable force platform

SANDS, William A., BOGDANIS, Gregory C., PENITENTE, Gabriella, DONTI, Olyvia, MCNEAL, Jeni R., BUTTERFIELD, Calin C., POEHLING, Robert A. and BARKER, Leland A.

Published version

SANDS, William A., BOGDANIS, Gregory C., PENITENTE, Gabriella, DONTI, Olyvia, MCNEAL, Jeni R., BUTTERFIELD, Calin C., POEHLING, Robert A. and BARKER, Leland A. (2020). Reliability and validity of a low-cost portable force platform. Isokinetics and Exercise Science, 28 (3), 247-253.

Title Page

Reliability and validity of a low-cost portable force platform

1. Primary Author:
William A. Sands, Ph.D., FACSM
U.S. Ski and Snowboard Association
2300 S 2100 E
Salt Lake City, UT 84109
385.887.1243
wmasands@hotmail.com

2. Gregory C. Bogdanis, Ph.D.
School of Physical Education and Sport Science
National and Kapodistrian University of Athens
41 Ethn. Antistasis Str. Dafni
172 37, Athens, Greece
+30210-7276115
gbogdanis@phed.uoa.gr

3. Gabriella Penitente, Ph.D.
Senior Lecturer in Sport and Exercise Biomechanics
Sheffield Hallam University
Collegiate Crescent
Sheffield, S10 2BP, UK
+44 (0)114 225 2304
g.penitente@shu.ac.uk

4. Olyvia Donti, Ph.D.
Sports Performance Laboratory
School of Physical Education & Sport Science,
National and Kapodistrian University of Athens
172 37 Athens, Greece.
odonti@phed.uoa.gr

5. Jeni R. McNeal, Ph.D. CSCS*D
Dept PEHR, 200 Phys Ed. Bldg
Eastern Washington University
Cheney, WA 99004, USA
509.359.2872
jeni_mcneal@hotmail.com

6. Calin C. Butterfield
U.S. Ski and Snowboard Association
1 Victory Lane
Park City, UT 84060, USA
435.714.1801
Calin.butterfield@usskiandsnowboard.org

7. Robert A. Poehling
U.S. Ski and Snowboard Association
1 Victory Lane
Park City, UT 84060, USA
435.602.9536
bob.poehling@usskiandsnowboard.org

8. Leland A. Barker
Department of Exercise Science and Pre-Health Professions
Creighton University
Omaha, NE USA 68178
LelandBarker@creighton.edu
402.280.5360

Abstract

BACKGROUND: A small, portable, inexpensive FP is a helpful test instrument in many strength and conditioning settings.

OBJECTIVE: The purpose of this study was to assess the reliability and validity of a portable FP.

METHODS: The FP was assessed statically for linearity and regionality using known weights and known weight placements across nine regions. Dynamic assessment was conducted by placing the FP on a laboratory-grade one-dimensional FP and performing static jumps, countermovement, and drop jumps with synchronized data acquisition. Frequency response of the FP was assessed by striking the top surface with a hammer.

RESULTS: Excellent static linearity (r>0.99), trivial differences in regional forces, excellent correlation between FPs in the static, countermovement, and anchored FP for the drop jump (all r>0.98) were observed. Frequency response from an impact was poor when the FP was not anchored. However, once anchored the FP showed a dominant frequency of more than 10 times the typical jump frequencies and excellent synchrony with the laboratory FP (r>0.98).

CONCLUSION: The FP showed good to excellent characteristics in the static and countermovement jumps and the drop jumps when anchored. The primary limitation of the FP is its small size and light weight.

Keywords: vertical jump; measurement; comparison; frequency response

Running Head: Portable Force Platform

No external funding was involved in this project

1. Introduction

Force platforms (FP) have become ubiquitous in the training evaluation of athletes and others both in terms of performance and injury rehabilitation. Force platforms provide information about the external forces involved in a movement; thus, helping coaches, scientists, and medical personnel evaluate various aspects of strength, speed, and power fitness [1]. Unfortunately, the typical laboratory-grade FP is prohibitively expensive, not easily portable, often requires additional expensive software, and may demand specialized personnel [2]. Laboratory-quality force platforms are usually built from steel, incorporate multiple sensitive strain gauges or load cells, are anchored to a concrete floor, and can measure forces and torques applied to the surface in three or more dimensions (i.e., up-down, left-right, and forward-backward). Investigators can use the types of information available from FPs but may also need instrumentation that is easy to use, small, portable, light, easy to interpret, reliable, valid, and affordable.

FPs in sport and rehabilitation settings are most commonly used to measure the vertical ground reaction forces of standing, squatting, and jumping [3, 4]. Restricting a force platform to measure only vertically directed forces (orthogonal to the surface of the force platform) dramatically reduces the complexity and cost of the platform. As such, a one-dimensional force platform requires the user to ignore the horizontal directions of force application – horizontal anterior/posterior and horizontal medial/lateral. Particularly in vertical jumping and squatting, the vast majority of forces applied by an athlete are vertical; thus, ignoring the other horizontal forces little to impair interpretation of the vertical force-time data for sport training prescriptions [5]. However, horizontal dimensions forces may add important information, especially for injury rehabilitation [6]. Investigators with interests in vertical force-time, impulse, peak force, rates of force development, acceleration, velocity, power, and change in position can use a one-dimensional FP to capture this information [7-9].

Sampling rate is usually under the control of the investigator and selectable via software. Typical sampling rates for one-dimensional FPs have ranged from less than 100 Hz to 1000 Hz. Determining the sample rate requires that one knows the skill or sub-skill duration of interest. For example, if the investigator is interested in an event that requires 0.02 s to complete, then the investigator should sample at least twice as fast as the maximum analog signal frequency of the event of interest (i.e., sample at 100 Hz). If the event takes one second, then the time between samples should be at least 0.5 seconds [10, 11]. Since vertical jumps require approximately 100 to 250 milliseconds from start to take-off, then sampling should be at least 200 Hz or greater. Two-hundred Hertz has been shown to be adequate for studying a countermovement jump [12, 13]. In contrast, this low sampling frequency (200 Hz) may not provide ample resolution with which to examine the changing forces that may occur during faster motions [1].

A small portable FP has been gaining acceptance and use among strength and conditioning professionals and medical personnel in training, laboratory, and clinical settings. However, despite one published study of the reliability and validity of athletes' performances using this type of FP [14], and one study of a similar two-dimensional FP [5], an in-depth study of the reliability and validity of this FP's characteristics has not been published. This study assessed the reliability and validity of the FP using multiple measurement methods, including static, dynamic, regional force evaluation, and frequency response. The tested hypotheses were that the FP would be reliable as measured across multiple test conditions, and valid in comparison to a more expensive laboratory quality FP.

2. METHODS

2.1 Subjects

This study addressed instrumentation rather than human subjects.

2.2 Instrumentation

The FP (FP1) under investigation was a Pasco Scientific one-dimensional force platform (Pasco Scientific, Inc., Roseville, CA, USA, Force Platform - PS 2141). The FP was 35 cm x 35 cm x 5.1 cm in size and 4 kg in mass. The FP1 was zeroed using a tare button and then observing a sample of the obtained zeroed force via software. The maximum sample rate for the FP1 was 1000 Hz, the resolution was 0.1 N, force range was -1100 N to +4400 N, and had overload protection up to 6600 N total. The structure of the FP1 is steel with a plastic housing constructed with embedded fiberglass for additional strength (Fig. 1). FP1 uses an Airlink Adapter (Pasco Scientific, Inc, Roseville, CA, USA PS-3200) (inset) that converts the analog signal to digital and transfers the data via USB cable and computer interface. Although the Airlink Adaptor can transfer data via Blue Tooth, the sampling rate drops to around 250 Hz. The wireless sampling option was not involved in this investigation. No electronic or digital filtering was used.

Assessment of reliability and validity of the FP1 required static and dynamic force-time analyses, measurement of FP1 regional differences, and determination of the natural frequency of the FP1. Data were obtained using Pasco Scientific, Inc., Capstone software (Version 1.13.2, Roseville, CA, USA).

2.3 Test Procedures

Static Force Evaluation: The static assessment consisted of placing a stack of ten weight training weight plates one at a time on FP1. The weights were centered on FP1, and the force output was captured and stored as each weight plate was added to the stack. The weight stack ranged from 20 kg to 230 kg (196.94 N to 2260.28 N).

Dynamic Force Evaluation: The dynamic assessment involved placing the FP1 on top of a Kistler Quattro Jump force platform (FP2) (Kistler Quattro Jump, Type 9290CD, 920 cm x 920 cm x 125 cm, linearity +/- 0.5%, range 0-10 kN, Winterthur, Switzerland). Both platforms were zeroed, and FP2 was calibrated with known weights as described by the manufacturer. Sampling of the platforms was performed simultaneously at 1000 Hz. Two trials of three jump types (static jump, countermovement jump, and drop jump) were conducted by one of the investigators for comparisons of FP1 and FP2. The drop jump was performed from a 40 cm block by one of the investigators (76.5 kg) landing, jumping, and landing again on FP1. The distance of the drop was 22 cm because of the heights of the FP1 and FP2. Instructions for the drop jump were to perform a countermovement drop jump [15-18]. The technique employed included an impact landing followed by self-selected moderate lower extremity flexion with ankle dorsiflexion followed by lower extremity extension and ankle plantar flexion. A “bounce” drop jump [19] was not permitted.

Regional Force Evaluation: A force platform is expected to detect forces uniformly across its top surface. In order to test the regional forces of the force platform, a known 25 kg weight was placed on top of a wood cube (5.1 cm^3) and placed in random order at nine different regions of FP1 (Fig. 2A). The regional analyses were conducted across the nine regions with five trials at each position selected at random [2].

Frequency Response: A problematic characteristic of force platforms is a response to impact that consists of "ringing" or vibration. Ideally, a force platform should not act similar to a trampoline by contributing to the rebound or recoil of an impact and should not vibrate when from an impact or push. However, nearly all objects will vibrate at a fundamental frequency when pushed, pulled, or struck [20, 21]. The platform's fundamental frequency can interfere with the detection of force during use. Natural frequency response was assessed by hitting the surface of the force platform with a hammer (0.80 kg). Examining the FP1 frequency response was particularly challenging because when the light force platform was struck with the hammer, the entire unit bounced upward off the floor indicating that the elastic characteristics of the materials and construction were not favorable for rapidly applied impact forces such as with a hammer.

In order to stop the bounces and stabilize FP1, the platform was fixed to a custom base structure incorporating 2.4 cm plywood boards supported by 1.7 cm by 10 cm wood supports. FP1 was secured using 6.35 cm x 0.7 cm machine bolts and nuts (Fig. 2B). FP1 uses adjustable furniture-like feet on the bottom of the force platform that allows height adjustment of each corner of the force platform to level the platform on uneven surfaces. The standard feet were removed and replaced by machine bolts and nuts. The bolts passed through a base structure via 0.7 cm drilled holes. The machine bolts were then attached tightly to the base of FP1. The sampling of the vibration of FP1 was 1000 Hz, which is somewhat slow for frequency analysis and a study limitation [11], but 1000 Hz was highest sampling rate the software allowed.

Statistical Analysis: Descriptive statistics, linear regression, repeated measures analysis of variance, and Fast-Fourier Transforms were calculated. Statistical significance was set at $\rho \leq 0.05$. Ninety-five percent confidence intervals, effect sizes ($\eta^2_{partial}$ and Cohen's d), and statistical power were also calculated when appropriate. Statistical analyses were conducted using Microsoft Excel (Version 1903, 2016 Redmond, WA, USA), IBM SPSS (Version 25.0.0.1, 2018), Capstone (Version 1.13.2, 2018, Version 1.13.2, Roseville, CA, USA), and Prostat (Version 6, Pearl River, NY, USA) software.

3. Results

3.1 Static Force Evaluation

Ten weight plates were used to assess the linearity of the FP1. The correlation of the known weights with the force values presented by the FP was r > 0.999+, $p < 0.0001$; adjusted r2 > 0.999+; standard error of the estimate was 0.507 N. The linear regression equation for FP1 was:

$$Y = 9.824\,(X) + 0.313 \tag{1}$$

Standard error of the intercept: 0.342 N; 95% CI = -0.474 to 1.105 N.

Standard error of the slope: 0.0023 N; 95% CI = 9.819 to 9.830 N.

3.2 Dynamic Force-Time Evaluation

Table 1 shows the results of the three, vertical jump-type comparisons with simultaneous sampling of FP1 lying on top of FP2. Three examples of the force-time curves of the static, countermovement, and drop jumps are depicted in Fig. 3 (A, B, C, and D) for visual comparisons. The problems with bouncing during the drop jump were addressed by anchoring FP1 using bolts and a heavy wood platform (Fig. 3D).

3.3 Regional Force Evaluation

Five trials of the nine regions of FP1 were conducted (Table 2). The 25 kg test mass weighed 245.15 N. The grand mean of the nine regions was 245.28 N, Std Error = 0.47, 95% CI Lower = 245.147 N, upper = 245.407 N ($F_{(8,32)}$ = 2.322, ρ = 0.043, η^2_{partial} = 0.367, power = 0.792).

3.4 Frequency Response

Five trials of hammer impacts at the center of the upper surface were used to assess the fundamental frequency of FP1. The five impact trials resulted in a mean of 195.36 ± 1.98 Hz. Fig. 4 shows an example of the Fast Fourier Transform procedure and the resulting power spectral density of the anchored FP1.

4. Discussion

The static assessment of the linearity of FP1 showed excellent results with r and r2 values greater than 0.99 and a low RMS value of approximately 0.5 N. FP1 presented a linear response to varying loads indicating that the device can be used to measure static forces with excellent validity.

The dynamic assessment also revealed excellent validity with r and r2 values greater than 0.98 for the static and countermovement jumps comparing FP1 and FP2 (Table 1). The RMS values for the static and countermovement jumps ranged from approximately 31 N to 83 N (3.16 kg to 8.46 kg). The slopes for the static and countermovement jumps were reasonably close to 1.0 (Mean = 1.0004 ± 0.042 N). Drop jump assessments using an unanchored FP1 showed lower correlation coefficients r ≈ 0.88 and r2 ≈ 0.77. The RMS values were unacceptably high at approximately 371 N and 384 N (37 kg and 39 kg) for trials 1 and 2, respectively. The force-time curve shown in Fig. 3C further supports the lack of direct correspondence between the two force platforms when performing drop jumps. Upon finding these results, FP1 was anchored using four bolts and obtained excellent correspondence with FP2 and a fundamental frequency which is greater than ten times the most rapid force applications of a drop jump. FP1's use for static and countermovement jumps is well justified, valid, and reliable.

Given that FP1 was designed to serve in high school and university physics labs, it is not surprising that an impact-related jump might deviate from an acceptable level of validity for use in a sport and laboratory setting. However, a simple bit of carpentry showed that the problem with FP1 and drop jumps lies with the mobility and lightness of the force platform. Once anchored FP1 performed well.

The FP1 regional measurements showed good validity and reliability across regions and trials (Table 2). The statistical results of this analysis were awkward. Despite the statistically significant ρ value, none of the pairwise comparisons reached statistical significance (all $\rho > 0.05$), none of the confidence intervals crossed zero, and the range of the differences across the trials and regions were trivially small (Mean = 0.53 N, SD = 0.17 N). Moreover, the positions’ mean force differences were of little practical significance.

The fundamental frequency of the unanchored FP1 was approximately 84 Hz, and the anchored FP1 showed a fundamental frequency of approximately 195 Hz. Although this value should be interpreted with caution, the frequency response was similar to that of a larger portable steel force platform with a mass of 30.7 kg [2]. A typical drop jump is likely the most demanding jump-type evaluated on this type of portable force platform. The relevant durations of two phases of the drop jump were 0.14 s to 0.17 s for the down or eccentric phase and 0.16 s to 0.19 s for the up or concentric phase [22]. The 84 Hz fundamental frequency of the unanchored FP1, was 4.4 to 6 times faster than the demands of the two rapid components of a drop jump. The anchored FP1 resulted in a fundamental frequency response that ranged from 10 to 12 times greater than the signal of interest [23]. Drop jumps appear to be at the limits of unanchored FP1's mechanical behavior while the anchored FP1 can be used for drop jump assessments.

5. Conclusion

The results of this experiment showed that FP1 was reliable and valid based on repeated force-time measurements and multiple jump types. The primary limitations of this force platform are its small size and mass. Those pursuing drop jumps with this type of force platform should anchor the force platform to the floor or to a heavy base to ensure that the force platform does not ring or vibrate at low frequencies or bias the jump data. With proper precautions, this force platform can serve the practical needs of field and laboratory assessment of vertical jumps and squats.

The small portable force platform examined here appears to be an excellent device for measuring weight, static positions, and static and countermovement jumps. Drop jumps are near the limit of the unanchored force platform’s ability to measure rapidly applied forces while providing reliable and valid data. Future research involving this type of portable force platform should explore the influence of bolting the platform to a heavy foundation such that the platform is fixed and not allowed to bounce. Given the low cost of FP1, the device is particularly well suited for strength and conditioning facilities and programs that have few financial resources and for field testing.

References

[1] Beckham G, Suchomel T, Mizuguchi S. Force plate use in performance monitoring and sport science testing. New Studies in Athletics. 2014;29(3):25-37.

[2] Major JA, Sands WA, McNeal JR, Paine DD, Kipp R. Design, construction, and validation of a portable one-dimensional force platform. J Strength Cond Res. 1998;12(1):37-41.

[3] Hornsby WG, Gentles JA, MacDonald CJ, Mizuguchi S, Ramsey MW, Stone MH. Maximum strength, rate of force development, jump height, and peak power alterations in weightlifters across five months of training. Sports. 2017;5(4).

[4] Kawamori N, Rossi SJ, Justice BD, Haff EE, Pistilli EE, O'Bryant HS, Stone, MH, Haff, GG. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. J Strength Cond Res. 2006;20(3):483-91.

[5] Silveira RP, Stergiou P, Carpes FP, de S. Castro FA, Katz L, Stefanyshyn DJ. Validity of a portable force platform for assessing biomechanical parameters in three different tasks. Sports Biomech. 2016:2-10.

[6] Eagles AN, Sayers MG, Lovell DI. Factors that influence ground reaction force profiles during counter movement jumping. J Sports Med Phys Fitness. 2017;57(514-520).

[7] Buckthorpe M, Morris J, Folland JP. Validity of vertical jump measurement devices. Journal of Sport Sciences. 2012;30(1):63-9.

[8] Schmidtbleicher D. Training for power events. In: Komi PV, editor. Strength and Power in Sport. Oxford, England: Blackwell Scientific Publications; 1992. p. 381-95.

[9] Verkhoshansky Y, Siff M. Supertraining. Rome, Italy: Ultimate Athlete Concepts; 2009 2009.

[10] Nyquist H. Certain topics in telegraph transmission theory. Trans AIEE. 1928;47:617-44.

[11] Winter DA. Biomechanics and Motor Control of Human Movement. New York, NY: John Wiley, & Sons; 1990.

[12] Hori N, Newton RU, Kawamori N, McGuigan MR, Kraemer WJ, Nosaka K. Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. J Strength Cond Res. 2009;23(3):874-82.

[13] Linthorne NP. Analysis of standing vertical jumps using a force platform. Amer J of Physics. 2001;69(11):1198-204.

[14] Lake J, Mundy P, Comfort P, McMahon JJ, Suchomel TJ, Carden P. Concurrent validity of a portable force plate using vertical jump force-time characteristics. J Appl Biomech. 2018;34(5):410-3.

[15] Bobbert MF. Drop jumping as a training method for jumping ability. Sports Med. 1990;9(1):7-22.

[16] Comyns TM, Brady CJ, Molloy J. Effect of attentional focus strategies on the biomechanical performance of the drop jump. J Strength Cond Res. 2019;33(3):626-32.

[17] Walsh M, Arampatzis A, Schade F, Brüggemann GP. The effect of drop jump starting height and contact time on power, work performed, and moment of force. J Strength Cond Res. 2004;18(3):561-6.

[18] Young WB, Pryor JF, Wilson GJ. Effect of instructions on characteristics of countermovement and drop jump performance. J Strength Cond Res. 1995;9(4):232-6.

[19] Bobbert MF, Huijing PA, Van Ingen Schenau GJ. Drop Jumping. II. The influence of dropping height on the biomechanics of drop jumping. Med Sci Sports Exerc. 1987;19(4):339-46.

[20] McMillan SK, Street GM, Heneghan M, Board WJ. Error analysis of impulse method in estimating CMJ height. Med Sci Sports Exerc. 2000;35(2):S222.

[21] Street G, McMillan S, Board W, Rasmussen M, Heneghan JM. Sources of error in determining countermovement jump height with the impulse method. J Appl Biomech. 2001;17:43-54.

[22] Bobbert MF, Huijing PA, Van Ingen Schenau GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. Med Sci Sports Exerc. 1987;19(4):332-8.

[23] Ramey MR. The use of force plates for jumping research. In: Terauds J, editor. Biomechanics in Sports. Del Mar, CA: Academic Publishers; 1983. p. 81-91.

Table 1.

Dynamic Force-Time Evaluation and Jump-Type Comparison

Jumps and Trials	R	R2	RMS	N		Coef	Std Err	Lower 95% CI	Upper 95% CI
Static Jump 1	0.99	0.996	31.62	2672	Interc	0.814	1.077	1.298	2.926
					Slope	1.007	0.001	1.005	1.009
Static Jump 2	0.98	0.972	83.90	2787	Interc	33.10	2.744	27.72	38.49
					Slope	0.940	0.003	0.934	0.946
Countermovement Jump 1	0.99	0.989	62.99	2415	Interc	-6.669	2.024	10.63	2.700
					Slope	1.016	0.002	1.012	1.020
Countermovement Jump 2	0.99	0.995	37.70	2935	Interc	-15.24	1.168	-17.54	-0.953
					Slope	1.0374	0.001	1.035	1.040
Unanchored Drop Jump 1	0.88	0.772	370.57	2707	Interc	27.178	8.512	10.48	43.869
					Slope	0.956	0.010	0.936	0.975
Unanchored Drop Jump 2	0.88	0.778	384.11	2317	Interc	50.927	9.004	33.27	68.584
					Slope	0.934	0.010	0.913	0.954
Anchored Drop Jump 1	0.99	0.997	46.49	3000	Interc	-1.236	1.034	-3.263	0.791
					Slope	1.003	0.001	1.001	1.005
Anchored Drop Jump 2	0.99	0.998	92.33	2982	Interc	0.543	2.094	-3.564	4.649
					Slope	0.986	0.002	0.982	0.999

RMS = Root mean square

Coef = Coefficient

Interc = Intercept

Table 2.

Regional Forces

Region	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	245.49	0.091	245.24	245.74
2	245.24	0.076	245.03	245.45
3	245.47	0.157	245.04	245.91
4	245.21	0.034	245.11	245.30
5	245.37	0.107	245.07	245.66
6	245.17	0.113	244.85	245.49
7	245.29	0.095	245.03	245.56
8	245.04	0.114	244.73	245.36
9	245.21	0.078	244.99	245.43

Figure Captions

Fig. 1. FP1 (in the center) was placed on top of FP2. Inset shows FP1 and white Air Link adapter (on the right with cables) of FP1.

Fig. 2. A) Regions for application of the 25 kg mass to assess if forces are the same across the top surface of the force platform. B) Anchoring method used to stabilize FP1.

Fig. 3. Force-time curve comparisons. Black = FP1, Grey = FP2. A) static jump, B) countermovement jump, C) drop jump with unanchored FP1, D) drop jump with anchored FP1.

Fig. 4. Power spectral density showing the fundamental frequency of an anchored FP1. Note that the dominant frequency occurs are approximately 195 Hz.

Fig 1.

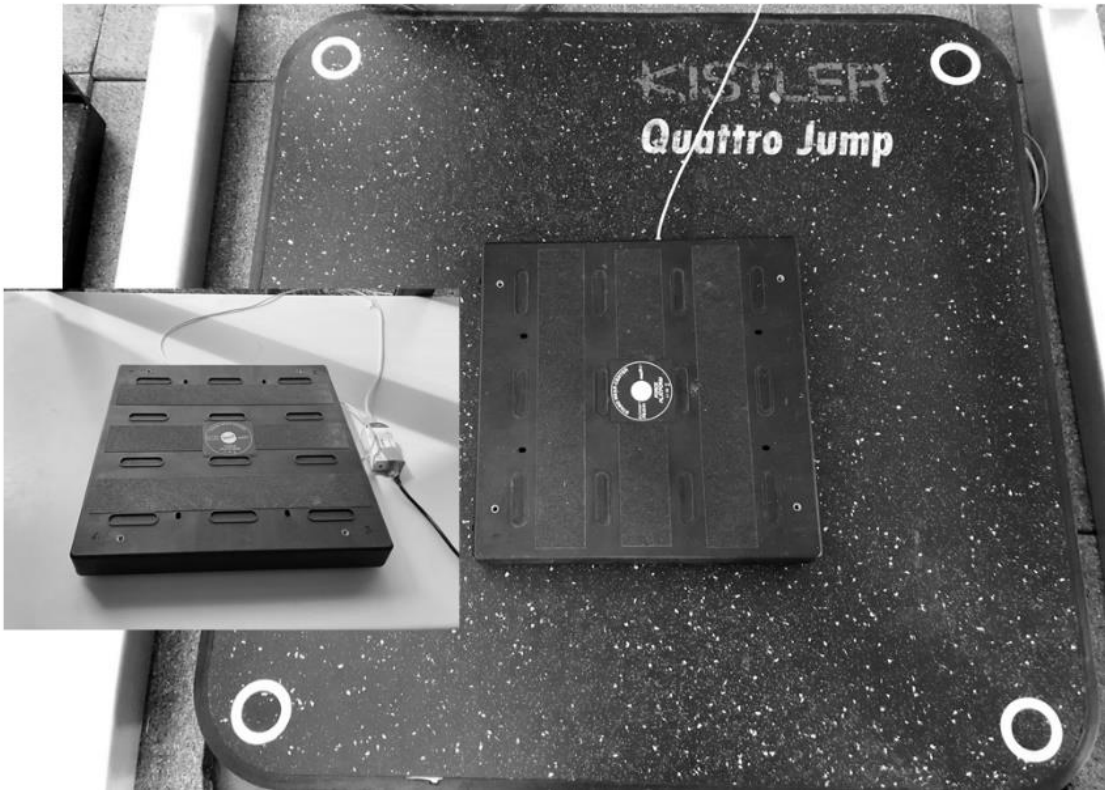

Fig. 1. FP1 (in the center) was placed on top of FP2. Inset shows FP1 and white Air Link adapter (on the right with cables) of FP1.

Fig 2.

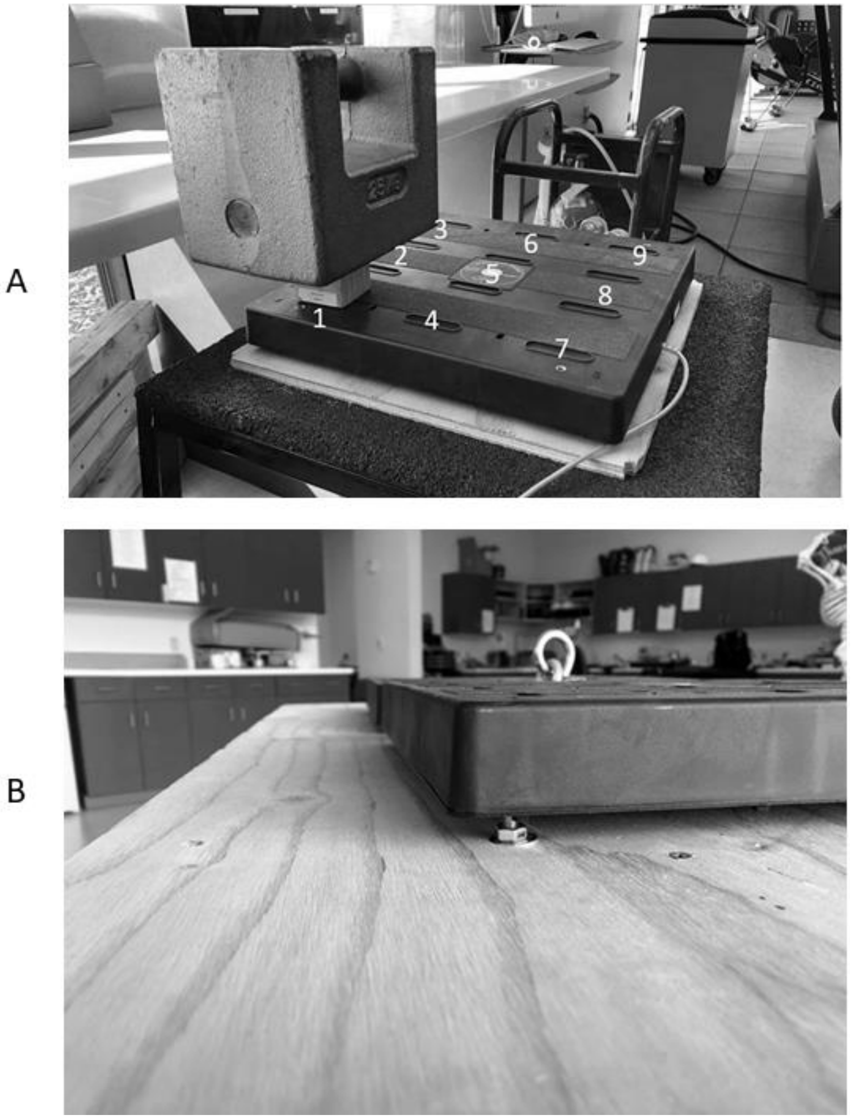

Fig. 2. A) Regions for application of the 25 kg mass to assess if forces are the same across the top surface of the force platform. B) Anchoring method used to stabilize FP1.

Fig 3.

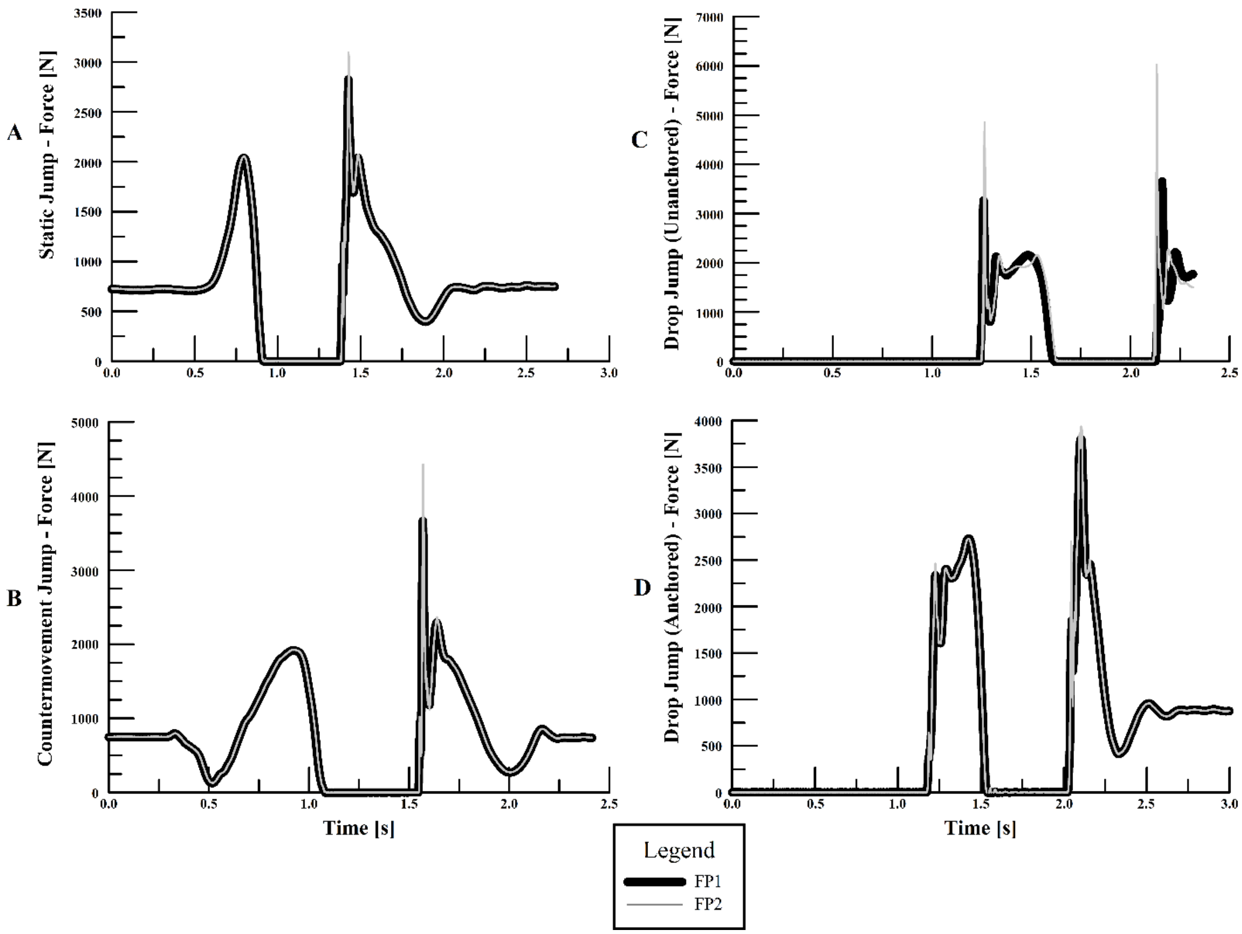

Fig. 3. Force-time curve comparisons. Black = FP1, Grey = FP2. A) static jump, B) countermovement jump, C) drop jump with unanchored FP1, D) drop jump with anchored FP1.

Fig 4.

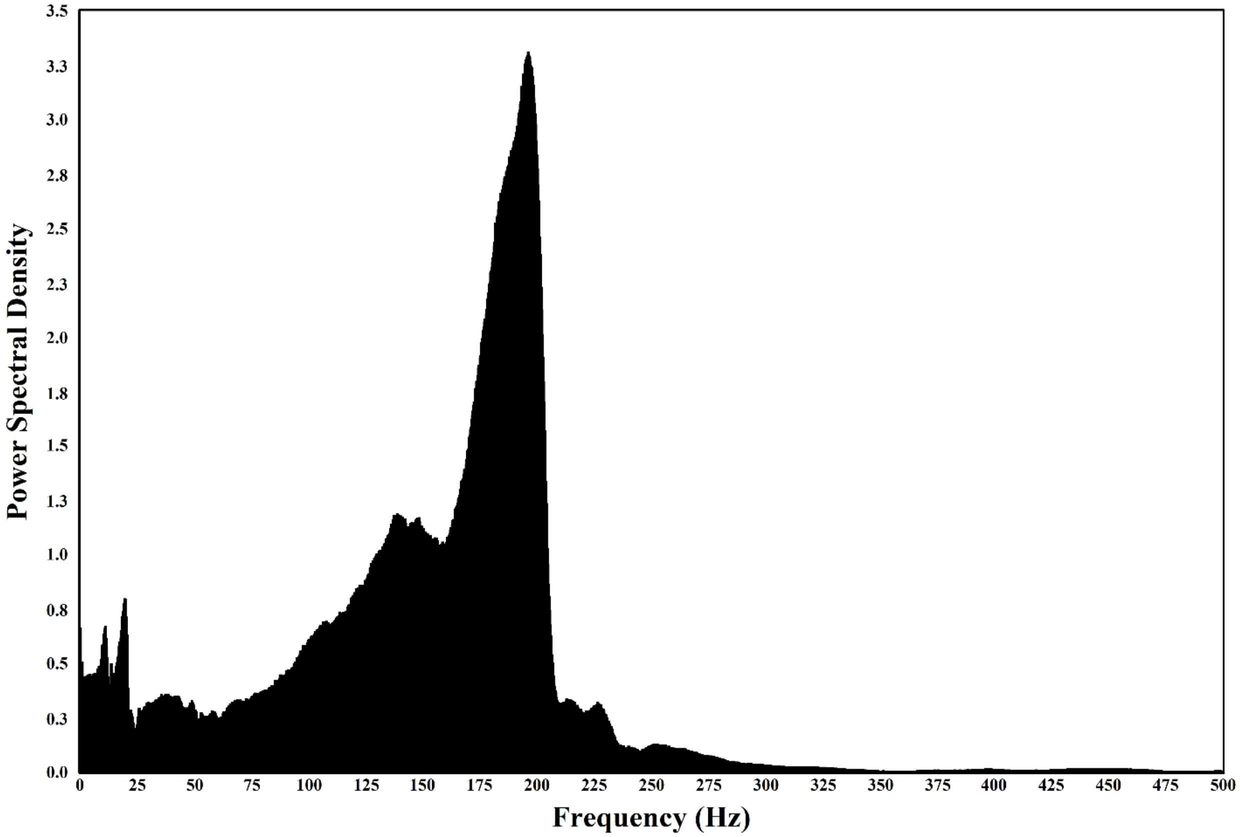

Fig. 4. Power spectral density showing the fundamental frequency of an anchored FP1. Note that the dominant frequency occurs are approximately 195 Hz.