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Title: Validity of Force-Velocity Profiling Assessed with a Pneumatic Leg Press Device

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Abstract

Purpose: The aim of this study was to examine the concurrent validity of force-velocity variables assessed across five Keiser leg press devices. **Methods:** A linear encoder and two independent force plates (Musclelab devices) were mounted on each of the five leg press devices. A total of 997 leg press executions, covering a wide range of forces and velocities, were performed by 14 participants (29±7 years, 181±5 cm, 82±8 kg) across the five devices. Average and peak force, velocity and power values were collected simultaneously from the Keiser and Musclelab devices for each repetition. Individual force-velocity (FV) profiles were fitted to each participant from peak and average force and velocity measurements. Theoretical maximal force (F_0), velocity (V_0), and power (P_{max}) were deduced from the FV-parameters. **Results:** Average and peak force and velocity had a coefficient of variation (CV) of 1.5 – 8.6%, near-perfect correlations (0.994 – 0.999) and a systematic bias of 0.7 – 7.1% when compared to reference measurements. Average and peak power showed larger CVs (11.6 and 17.2%), despite excellent correlations (0.977 and 0.952) and trivial to small biases (3.9 and 8.4%). Extrapolated FV-variables showed near-perfect correlations (0.983 – 0.997) with trivial to small biases (1.4 – 11.2%) and an CV of 1.4 – 5.9%. **Conclusion:** The Keiser leg press device can obtain valid measurements over a wide range of forces and velocities across different devices. To accurately measure power, P_{max} calculated from the FV-profile is recommended over average and peak power values from single repetitions, due to lower random error observed for P_{max}.

Keywords: Performance, strength testing, athlete assessment, force plate, linear encoder

Introduction

The ability to produce force over a range of velocities is fundamental in most sport disciplines [1,2]. Based on the presumption that the relationship between force and velocity in whole body, multi-joint movements is linear, the theoretical maximal force (F_0) and theoretical maximal velocity (V_0) of the athlete can be determined from linear regression[3,4]. This information can be interpreted as an athlete's individual ratio between force and velocity, i.e., the slope of the force-velocity (FV) profile (S_{FV}). Further, the athlete´s theoretical maximal power (force × velocity at optimal loads; P_{max}), which is highly correlated with athletic performance, can be determined from the FV-profile[2]. Indeed, FV-profiling has recently received increased attention as a means of monitoring training adaptations[5-7] and serving as basis for individual training prescriptions for athletes[7-10].

In practice, the FV-profile is often assessed by performing vertical jumps with incremental loads[11]. A limitation with vertical jumping is the technical demand of jumping with heavy loads[12], where it is challenging to jump with loads close to F_0[10]. However, more importantly, as the bodyweight is the lightest assessable load, the highest measured velocity is typically far from V_0[10,13]. Indeed, these can be some of the reasons why FV-profiles from loaded jumps have relatively poor reliability[10,14]. Preferably, the FV-profile should include measurements close to both F_0 and V_0, as previous studies have shown that extensive extrapolation of the regression line may lead to inaccuracies in estimation of F_0 and V_0, which in turn affects the reliability and validity of the S_{FV} and P_{max}[15,16].

The pneumatic resistance-based Keiser leg press (utilizing air pressure as means of resistance[17]) is a commercial device available in many sports and research facilities all over the world (applied in over 30 original, peer-reviewed papers the last four years)[5,18-22]. Compared to weight-based exercises, the resistance from the pneumatic leg press is minimally influenced by inertia and bodyweight. This has several advantages, such as i) the lack of need for deaccelerating a large mass when performing maximal attempts and ii) making it achievable to assess extremely low resistances, as the resistance is not influenced by acceleration. Resultingly, attempts close to both F_0 and V_0 -intercepts are measurable. Due to the lower extrapolation, it is possible that FV-parameters can be obtained with higher reliability using a pneumatic leg press device compared to those of vertical jumping[10,22].

The pneumatic device measures compression forces of the piston in the air cylinder[17]. This measurement of force is arguably less direct than other approaches such as reaction forces obtained with force plates, which are commonly considered gold-standard for force measurements during ballistic movements[23]. For athletes and coaches, it is imperative to know whether values obtained from testing are accurate, and how these values can be interpreted, e.g., compared to force plate data. Moreover, as test results are commonly compared within- and between athletes, in both sports and research, it is of great interest to know whether measurements obtained across different Keiser leg press devices are comparable. To date, the validity of the Keiser leg press and the variability of force, velocity and power measurements across different devices, has never been examined.

Hence, the aims of this study were to i) examine the concurrent validity of force-velocity variables assessed by the Keiser leg press device against force plates and a linear encoder and ii) compare measurements across five Keiser leg press devices.

Methods

Experimental approach

To validate measurements by the Keiser leg press device, we simultaneously collected force and velocity data from two force plates and a linear encoder, mounted on the Keiser leg press (Figure 1). To compare measurements across devices, criterion data were collected using identical equipment on the five Keiser leg press devices.

In total (across all devices and participants), 997 repetitions were performed over a large range of forces and velocities (peak values: 298 – 4056 N and 0.2 – 2.9 ms^{-1}). We included both submaximal and maximal efforts, as described below (Protocol 1 and 2). This approach was chosen to encompass the typical range of force and velocity values collected from athletes assessed at the Norwegian Olympic centers (based on >400 athletes, mean±2SD: force 1770±1440 N, velocity 1.6±1.2 ms^{-1}), hence validating a large range of data points including both minimal and large accelerations.

*** Figure 1 about here ***

Participants

Fourteen participants (29±7 years, 181±5 cm, 82±8 kg) were included in this study and all were regularly active and from a variety of sporting backgrounds. The participants had comparable lower body power capabilities to earlier investigations of competitive athletes: 1661±389 W vs. 1795±472 W, respectively[10] (peak power derived from Keiser FV-profiles, based on average values – see *Data analysis* below).

The study was performed in accordance with the Declaration of Helsinki and all participants gave their consent to participate in this study.

Equipment and set-up

Two independent force plates (32x20 cm; Musclelab, Ergotest Innovation, AS, Langesund, Norway) were anchored to each of the foot-pedals of the Keiser leg press device (Keiser Air300, A420; Fresno CA, United States; Figure 2). The string of a linear encoder (Musclelab, Ergotest Innovation AS, Langesund, Norway) was attached horizontally to the right foot-pedal of the Keiser device with straps and tape (Figure 2). This set-up was similar across all five devices. The encoder and the force plates from Musclelab were synchronized via a Data Synchronization Unit (Musclelab, Ergotest Innovation, AS, Langesund, Norway). Musclelab data were sampled at 200 Hz, while Keiser data were sampled at 400 Hz.

Figure 2 about here

Test procedures

All participants were familiarized with the test equipment and protocols prior to testing. Each participant warmed up by performing 10 – 20 repetitions with self-selected loads.

The position of the seat was adjusted for each participant to result in approximately 75° of knee flexion when feet were placed on the foot-pedals. Both force plates were zeroed before each recording to avoid system drift. These test procedures were similar for protocols 1 and 2, and across all five devices.

Protocol 1- Submaximal effort

All 14 participants performed this protocol. Each repetition was performed as a single repetition with submaximal effort (except for repetitions close to the maximal strength of the participants). The participants were instructed to increase the force in a controlled manner, until the pedals moved, thus, avoiding large accelerations. The protocol was implemented with increasing loads, starting with the lightest, ending with the heaviest load (ranging from 25 – 450 kgf). Inter-repetition rest periods ranged from 10 seconds to 4 minutes depending on the progressing load (longer rest periods before heavy loads).

Protocol 2- Maximal effort

Of the 14 participants, 11 performed this protocol. All loads were provided by the Keiser device´s pre-programmed 10-step test. The 10-step protocol was performed with progressive, increasing resistance (ranging from 20 – 420 kgf), performed as single repetitions, where each repetition was performed with maximal efforts, i.e., the participants were instructed to move as fast as possible. The inter-repetition rest periods ranged from 20 seconds to 3 minutes depending on the progressing load.

Data analysis

All data were processed using MATLAB (R2020a version, MathWorks, Inc., Natick, USA). The data were checked for outliers (n=15) and 997 executions were included in the analysis. Data from Musclelab was up-sampled to 400 Hz using linear interpolation, to match the sampling frequency of Keiser. Force data from the Keiser device and force plates were filtered using a 2nd order bidirectional Butterworth low-pass filter with a cutoff frequency of 20 Hz, which was determined from residual analysis.

From single repetitions, average values for Keiser and Musclelab measurements were taken from the phase of leg extension in the interval of 5 – 95% of the displacement curve (as the in-built Keiser software; Supplementary Figure 1). Displacement was calculated using numerical integration (trapezoidal rule) of the Keiser device's velocity measurements (Supplementary content 1). Peak values were set as the instantaneous peak value, independent of the interval range used for average values (as the in-built Keiser software) (Supplementary Figure 2).

To account for additional influence of inertial forces of the force plates, the mass of the force plates (13.4 kg) was multiplied by the instantaneous acceleration from the encoder and subtracted from the force measurements obtained by the force plates. Force values are presented as the sum of the right and left leg. Velocity values are presented for the right pedal and cylinder, respectively. Power values were calculated as force times velocity and are hence presented as the sum of the right and left leg. The individual FV-profiles were calculated using linear regression on all repetitions of each participant, with F as the dependent variable and v as the independent variable. The regression was done using both average and peak force and velocity values from protocol 2 (maximal effort attempts). The FV-parameters were defined as F_0: y-intercept of regression line; V_0: x-intercept of regression line; P_{max}: $F_0 \cdot V_0/4$; S_{FV}: slope of the regression line.

Statistical analysis

All data are presented as mean ± standard deviation (SD) unless stated otherwise. Differences between Keiser and Musclelab measurements were evaluated through mean bias and regression statistics. Mean bias is presented as raw values, percentage, and standardized differences (mean difference divided by SD of sample). The standardized differences were qualitatively interpreted using the scale: <0.2 Trivial; <0.6 Small; <1.2 Moderate; <2 Large; <4 Very large; >4 Extremely large[24,25]. The probability of bias was evaluated with a paired sample *t*-test and non-clinical magnitude-based inferences (MBI)[26]. Qualitative assessment of probability was categorized followingly: Most unlikely; 0 – 0.5%, very unlikely; 0.5 – 5%, unlikely; 5 – 25%, possibly; 25 – 75%, likely; 75 – 97.5%, very likely; 97.5 – 99.5%, most likely; 99.5 – 100%. Threshold values for the magnitude of mean bias were the smallest worthwhile change (SWC (0.2*between-subject SD)) for each respective variable. The SWC is based on values from a representative athletic sample from previous investigations[10]. Additionally, for comparing methods, the standard error of estimates (SEE), coefficient of variation (CV%, calculated as the SEE in percent) and intraclass correlation coefficient (ICC (1,k)) of the linear regression were calculated. To examine differences in bias across devices, the mean percent bias for each device was compared to the mean percent bias of the total sample using MBI with the mentioned qualitative probabilities. Further, mean bias was evaluated at predicted values at low, moderate, and high values corresponding to 20, 50 and 80% of the sample range for the respective variables. Following, the mean percent bias was also compared across devices to the total sample bias at low, moderate, and high values for repetitions performed at maximal and submaximal effort. Threshold values for the differences across devices were the test-retest typical error (CV%) obtained from a representative athletic sample from a previous investigation[10], corresponding to 4.8, 2.4 and 5.3% for force, velocity and power, respectively. Acceptable CV% was considered ≤10%[27,28]. Compatibility limits (CL) for all analyses were set at 95%. Statistical analysis was performed using MATLAB (R2020a version, MathWorks, Inc., Natick, USA) and a custom-made excel spreadsheet[29].

Results

There were significant differences between methods for all measures except for peak force, however, these differences were of unclear, trivial, or small magnitude (Table 1). The systematic bias for force, velocity and power ranged from -8.4 to 4.7% and the random error (CV%) ranged from 1.5 to 17.2%, for both average and peak values. The systematic and random error of the FV-variables (F_0, V_0, P_{max} and S_{FV}) ranged from -5.7 to 11.2% and 1.4 to 5.9%, respectively (See Table 1 and Figure 3).

*** Figure 3 about here ***

*** Figure 4 about here ***

*** Figure 5 about here ***

*** Table 1 about here ***

For comparisons across devices, the deviation from the total sample bias for all devices was trivial and ranged from -1.2 to 2.1%, -0.9 to 1.7% and -2.7 to 3.2% for force, velocity, and power, respectively (Supplementary Table 1). Including only submaximal repetitions (*n*=467), the difference in bias was trivial and ranged from -3.9 to 4.4%, -1.4 to 1.2% and -5.0 to 1.9% for force, velocity, and power, respectively. For maximal effort attempts (*n*=530), the difference in bias ranged from very likely trivial to very likely negative, for force (-6.2 to 1.8%) and power (-8.5 to 2.7%), while for velocity the differences were most likely trivial (-0.9 to 1.9%).

For repetitions performed with submaximal effort, the systematic bias was trivial (-8.0 to 4.5%) for low, moderate, and high values, across all measurements. The force, velocity, and power measurements had biases ranging from -9.0 to -0.5, 1.5 to 6.8 and -31.0 to -10.0%, respectively (Table 2), from the repetitions performed with maximal effort.

*** Table 2 about here ***

Discussion

This is the first study to investigate the concurrent validity of the Keiser pneumatic leg press device. The main finding was that valid measurements are obtained with the Keiser leg press device over a wide range of forces and velocities and also across different devices. However, it is important to be aware that differences between the Keiser device and force plates and linear encoder are significant, albeit mostly trivial. Researchers and coaches should be aware that the Keiser device underestimated force and power measures when performing repetitions with maximal effort at low resistance.

Force measurements

The main difference between the force measurements of the Keiser device and force plates is that the pneumatic leg press measures compression forces in the air cylinder, whilst the force plates measure reaction forces. These differences result in inertial forces being captured in the force plates, but not at the cylinder, which appears to have affected the force comparisons in two ways.

Firstly, the mass of the force plates, foot-pedals and lever arms of the Keiser device caused considerable inertia captured by the force plates but not by the Keiser device. To account for the force plates (normally not attached to the foot-pedals), the mass of the force plates and the resulting acceleration from the force plate recordings were subtracted (see *Data analysis*). Nevertheless, there remained a considerable mass of the foot-pedals and lever arms connected to the cylinder, that are unaccounted for in the Keiser device´s force measurements. The inertia of this mass was evident by looking at differences in bias between the submaximal and maximal protocols where the accelerations were different, which in turn would have influenced the inertial forces that were possible to examine (F=ma). As an example, the bias for average values at low forces with maximal effort was -9.2%. For submaximal efforts, the bias was -2.7%, indicating that the force plates registered higher forces at maximal- compared with submaximal efforts, especially at low forces (Table 2).

A secondary effect of inertia was that the reaction forces measured by the force plates would be larger at the beginning of the movement and decrease towards the end of the extension phase during trials with high accelerations. Concurrently, as the Keiser device measures compression forces at the cylinder, an opposite pattern would appear where peak force occurs at the end of the extension phase. Consequently, peak force occurs at different parts of the extension phase; yet, they were numerically comparable. As the average values are calculated over the entire range of motion, including both the accelerating and decelerating phase, this seems to explain the slightly larger bias at average, compared with peak values (Table 1).

Taken together, as the Keiser device´s force measurements are not influenced by inertia, this appears to result in a trivial systematic bias for average force measurements measured by the Keiser device.

Velocity measurements

Velocity recordings from both the Keiser device and encoder were calculated as the derivate position over time, hence, the main difference must have been where the change in position was measured. Due to the construction of the apparatus, a full extension of the foot-pedals (where the encoder was attached) consisted of approximately two times larger displacement compared to the cylinder. To account for this, the in-built Keiser software recalculates the values at the cylinder to match those of the foot-pedals (as described in the Keiser A420 manual). These recalculations seem reasonably accurate for peak measurements. However, the bias systematically increased with increasing velocities for average values (Table 2 and Figure 5). Interestingly, due to the construction of the apparatus (angular rotations over several axes), the relationship between the position of the cylinder and the position of the encoder was nonlinear. This nonlinear position change between the cylinder and encoder creates larger bias at average values, as these are taken from the entire range of motion, compared with peak measurements. Moreover, larger position changes at the end of the extension phase in the cylinder compared with the encoder, would in turn lead to higher measured velocities by the Keiser device. These assumptions could explain the tendency for the Keiser device to measure slightly higher velocities than the encoder (Table 1 and Figure 5).

Since it was harder to achieve full plantar flexion at high forces/low velocities, the participants performed most of the repetitions with greater range of motion at high velocities than at low velocities. Additionally, at high velocities, there may have been some movement of the participants – sliding forward due to a momentum generated by the movement of the center of mass as the legs extend (the participants were not strapped to the chair). This could account for significantly larger position changes at higher velocities and further explain why the bias increased from 2.9% at low velocities to 6.8% at high velocities (Table 2).

Because the Keiser software recalculates values of the cylinder to match those of the foot-pedals, the bias in peak velocity was non-existing. However, as the nonlinear position change remains unaccounted for, this resulted in a systematic bias for velocity measurements when averaged over the full range of motion.

Power measurements

Power is calculated as force times velocity, and the power data were condemned to reflect the systematic bias of the force and velocity measurements. However, this would not contribute greatly to the observed bias, as will be discussed below.

Interestingly, both mean bias and the random error were large, especially for attempts at maximal efforts (Table 2). The influence of inertial forces was larger for peak and average power measurements compared to the force measurements. This is due to power being the instantaneous calculation of force and velocity, where a slight shift in the force curve (discussed above), causes cumulative differences in the power calculations. For example, for a single attempt with maximal effort, the shift in the force curve caused by inertia produced an instantaneous peak power of 3082 W for the force plates and encoder and 2605 W for the Keiser device. Both measurement systems measured similar average force (1072 vs. 1054 N) and velocity (1.68 vs. 1.69 ms^{-1}), but as the shifted force curve was multiplied by velocity, larger differences in peak power were observed. Contrary, when attempts were performed with submaximal efforts the effect of inertia was non-existing and the bias was trivial, illustrated by the bias of -27% at maximal efforts vs. -4% at submaximal efforts (Table 2).

To sum up, a systematic bias in the force and velocity measurements could affect the power measurements to a small degree but the power measurements were mostly influenced by the shift in the force curves due to inertia.

Force-velocity profile

The bias in F_0, V_0, and S_{FV} observed for peak values seems reasonable as both peak force and velocity was obtained from different parts of the extension phase between the Keiser device and force plates and encoder (discussed above). Hence, FV-profiling taken from average values has larger conceptual validity.

Moreover, in addition to small systematic bias in the FV-profile from average measurements, the random errors were relatively small compared to random errors of individual attempts (1.4 – 2.8% vs. 1.5 – 11.6%, Table 1). As the random error decreases when calculated from several attempts, this reflects a strength of the FV-profile to measure force, velocity, and power. Notably, the bias for P_{max} was low compared with the power measurements discussed above (Table 1 and 2). This is because P_{max} was calculated from the respective regression lines from individual force and velocity values, thus, circumventing the impact of the shift in the force curves.

Hence, FV-profiling should be obtained from average rather than peak values. Moreover, P_{max} is a more robust measurement of power than average and peak power measurements.

Differences across devices

Due to the influence of inertia on the measurements (discussed above), the systematic differences across devices (Supplementary Table 1) were influenced by between-subject characteristics in power capabilities, as well as differences in efforts produced. The latter explains the substantially lower difference across devices for submaximal compared with maximal efforts in force and power measurements. Nevertheless, both for submaximal and maximal efforts, the systematic bias across devices (-5 to 4.4%) was lower than the random error (1.5 to 17.2%) (Supplementary Table 1). Additionally, these differences across devices were comparable to the test-retest typical error (±5%) and the SWC (±5%) measured previously in a representative athletic sample[10]. Consequently, the devices can be used interchangeably.

Practical Applications

Testing criterion validity necessitates that the “gold-standard” itself is valid. In our case, we used force plates with one-dimensional force transducers and a relatively low sampling frequency (200 Hz). Load-tests and a control for signal drift between recordings were conducted prior to each test session, but we have no validation of the force plates *in situ*. However, there are no reasons to believe that the force plate data was invalid, but we acknowledge that some of the variation in our data is probably due to the accuracy of the criterion measurements.

A low number of participants were included in this study and their performance characteristics across Keiser devices differed to some extent (different participants at different devices). However, we were interested in comparing raw data between the Keiser device and the force plates (force against force) and encoder (velocity against velocity) across a range of values that we typically see among athletes at the Norwegian Olympic training center. We considered the share number of repetitions (~ 1000) and not the number of participants, and our methodological approach complied with these terms.

The Keiser leg press is used in many sports facilities worldwide for testing and monitoring athletes; moreover, the device has been used in several recent research studies[5,18-22]. We confirm that the Keiser leg press device records valid force and velocity data. This implies that athletes and coaches can use the Keiser leg press device for repeated testing and monitoring of athletes.

Conclusion

The Keiser leg press device obtained valid measurements over a wide range of forces and velocities, which was confirmed across devices. Differences across devices were mostly trivial but varied depending on the range of values and efforts being assessed. The Keiser leg press devices can be used interchangeably within a range of ±5% to measure force, velocity and power. Researchers and coaches should be especially aware of the bias in force that can be observed when performing single repetitions with maximal effort at low resistance. Similarly, moderate to large bias can occur in the measures of power when performing single repetitions with maximal effort (up to 30%). The extrapolated FV-variables (F_0, V_0, P_{max} and S_{FV}) obtained from average force and velocity values showed trivial systematic bias (<5%) with low random errors (<3%) and should be preferred over peak values. To accurately measure power, P_{max} obtained from the FV-profile is recommended over average and peak power from single repetitions.

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Conflict of interest

The authors declare no commercial nor financial interests to the equipment used in the present study. No external funding was received for the present study.

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Figure captions

Figure 1 Experimental set-up in the present study. Two independent force plates and a linear encoder (Musclelab, Ergotest Innovation, AS, Langesund, Norway) mounted on the Keiser leg press device (Keiser Air300, A420; Fresno CA, United States).

Figure 2 Experimental set-up in the present study. The force plates were anchored to the Keiser foot-plates by a custom-made iron frame. The linear encoder was anchored to the back of the seat with straps, and the string of the linear encoder was attached horizontally to the right foot-pedal with tape.

Figure 3 Force-velocity profiles for the 11 participants performing protocol 2 (maximal effort attempts) obtained from average force and velocity values for the Keiser and Musclelab devices.

Figure 4 Scatterplots of the relationship between the measurements obtained by the Keiser and Musclelab devices. *ICC: Intraclass correlation coefficient, N=Newtons, ms^{-1}= Meter per seconds, W=Watts*

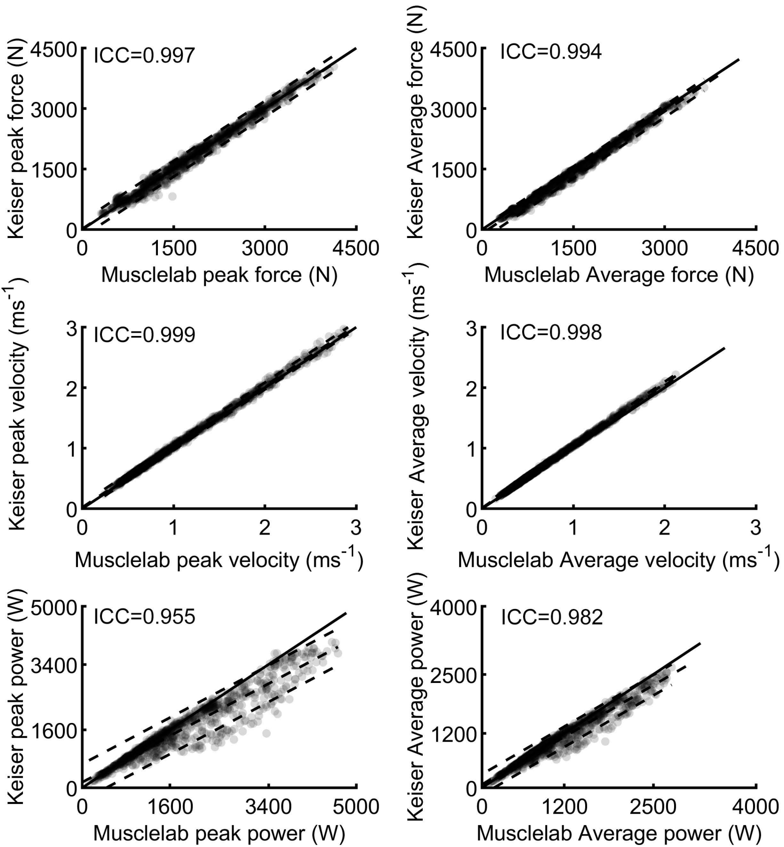
Figure 5 Bland-Altman plots of the relationship between the measurements obtained by the Keiser and the Musclelab devices. *SEE: Standard error of estimate, N=Newtons, ms^{-1}= Meter per seconds, W=Watts*

Tables

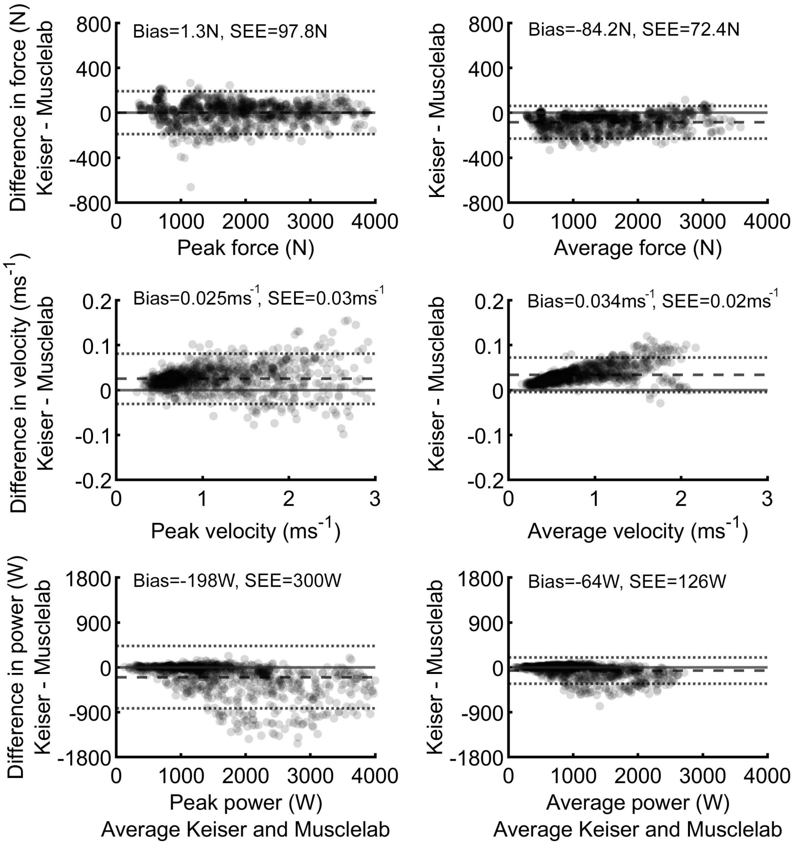
Table 1 Comparison of Keiser and Musclelab measurements for all devices combined

Table 2 Predicted bias from repetitions performed with maximal and submaximal efforts for all devices combined


KEISER
KEISER
RESISTANCE
TARGET REPS
LEFT REPS
RIGHT REPS
SET
OPERATION



ICC=0.997
Keiser peak force (N)
Musclelab peak force (N)
ICC=0.994
Keiser Average force (N)
Musclelab Average force (N)
ICC=0.999
Keiser peak velocity (ms-1)
Musclelab peak velocity (ms-1)
ICC=0.998
Keiser Average velocity (ms-1)
Musclelab Average velocity (ms-1)
ICC=0.955
Keiser peak power (W)
Musclelab peak power (W)
ICC=0.982
Keiser Average power (W)
Musclelab Average power (W)



Bias=1.3N, SEE=97.8N
Difference in force (N)
Keiser - Musclelab
Peak force (N)
Bias=-84.2N, SEE=72.4N
Keiser - Musclelab
Average force (N)
Bias=0.025ms-1, SEE=0.03ms-1
Difference in velocity (ms-1)
Keiser - Musclelab
Peak velocity (ms-1)
Bias=0.034ms-1, SEE=0.02ms-1
Keiser - Musclelab
Average velocity (ms-1)
Bias=-198W, SEE=300W
Difference in power (W)
Keiser - Musclelab
Peak power (W)
Average Keiser and Musclelab
Bias=-64W, SEE=126W
Keiser - Musclelab
Average power (W)
Average Keiser and Musclelab

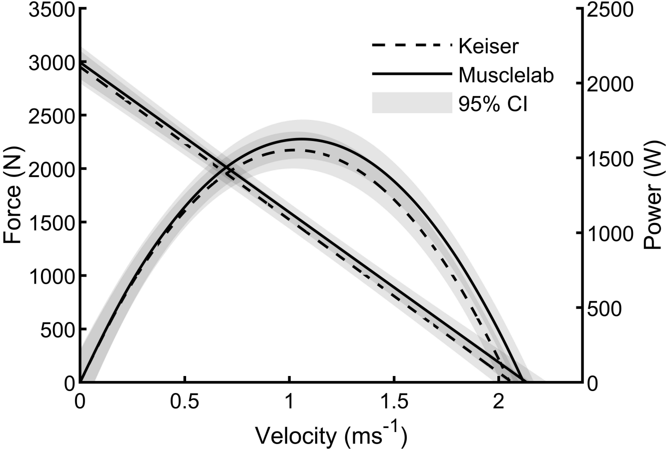

Keiser
Musclelab
95% CI
Force (N)
Power (W)
Velocity (ms^{-1})
3500
3000
2500
2000
1500
1000
500
0
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2

Table 1 Comparison of Keiser and Musclelab measurements for all devices combined

		Mean Musclelab(±SD)	Mean Keiser (±SD)	Mean bias (±SD)	Mean bias % (±SD)	Standardized difference (±CL)	Qualitative inference and probability for bias	SEE (±CL)	CV% (±CL)	ICC (±CL)
Average values	Force (N)	1558 ± 742	1474 ± 752	-84.2 ± 73.8***	-7.1 ± 7.5	-0.11 ± 0.01	Trivial (Very likely trivial)	72.4 ± 3.2	7.2 ± 0.3	0.994 ± 0.001
	Velocity (ms $^{-1}$)	0.79 ± 0.44	0.83 ± 0.45	0.034 ± 0.02***	4.7 ± 1.7	0.08 ± 0.00	Trivial (Most likely trivial)	0.02 ± 0.00	1.5 ± 0.1	0.998 ± 0.000
	Power (W)	1105 ± 584	1041 ± 524	-64.1 ± 134***	-3.9 ± 9.7	-0.11 ± 0.01	Trivial (Likely trivial)	126.0 ± 5.5	11.6 ± 0.5	0.982 ± 0.002
	F_0 (N)	3068 ± 676	3025 ± 672	-43.3 ± 54.0*	-1.4 ± 1.8	-0.06 ± 0.05	Trivial (unclear)	56.9 ± 32.4	2.0 ± 1.1	0.998 ± 0.004
	V_0 (ms^{-1})	2.14 ± 0.26	2.07 ± 0.23	-0.072 ± 0.04***	-3.3 ± 1.5	-0.28 ± 0.10	Small (unclear)	0.03 ± 0.02	1.4 ± 0.8	0.972 ± 0.046
	P_{max} (W)	1647 ± 408	1570 ± 390	-77.3 ± 39.7***	-4.6 ± 2.2	-0.19 ± 0.07	Trivial (unclear)	38.0 ± 21.6	2.4 ± 1.4	0.988 ± 0.019
	S_{FV} (N/ms^{-1})	-1448 ± 372	-1474 ± 369	-25.8 ± 36.7*	1.9 ± 2.7	-0.07 ± 0.07	Trivial (unclear)	38.6 ± 22	2.8 ± 1.6	0.997 ± 0.006
Peak values	Force (N)	1866 ± 856	1868 ± 855	1.3 ± 97.8	0.7 ± 8.3	0.00 ± 0.01	Trivial (Most likely trivial)	97.8 ± 4.3	8.6 ± 0.4	0.997 ± 0.000
	Velocity (ms $^{-1}$)	1.11 ± 0.61	1.14 ± 0.61	0.025 ± 0.029***	2.7 ± 2.5	0.04 ± 0.00	Trivial (Very likely trivial)	0.03 ± 0.00	2.3 ± 0.1	0.999 ± 0.000
	Power (W)	1749 ± 981	1550 ± 823	-198.7 ± 319.4***	-8.4 ± 12.9	-0.20 ± 0.02	Small (Very likely trivial)	300.0 ± 13.0	17.2 ± 0.8	0.955 ± 0.006
	F_0 (N)	3588 ± 833	3738 ± 803	149.9 ± 99.1***	4.5 ± 3.2	0.18 ± 0.08	Trivial (unclear)	101.0 ± 57.0	3.0 ± 1.7	0.988 ± 0.019
	V_0 (ms^{-1})	3.23 ± 0.54	3.02 ± 0.4	-0.203 ± 0.165**	-5.7 ± 4.1	-0.37 ± 0.21	Small (unclear)	0.1 ± 0.06	3.0 ± 1.8	0.925 ± 0.122
	P_{max} (W)	2885 ± 767	2832 ± 732	-52.8 ± 68.8*	-1.6 ± 2.2	-0.07 ± 0.06	Trivial (unclear)	64.2 ± 36.5	2.1 ± 1.2	0.997 ± 0.005
	S_{FV} (N/ms^{-1})	-1146 ± 350	-1254 ± 314	-108.7 ± 62.5***	11.2 ± 8.2	-0.31 ± 0.12	Small (unclear)	57.0 ± 32.4	5.9 ± 3.5	0.965 ± 0.057

*Force, velocity, and power values from both protocols (997 repetition and 14 participants). FV-variables are from the maximal effort protocol including FV-profiles from 11 participants. SEE: Standard error of estimate. SD: Standard deviation, CL: 95% Compatibility limits. ICC: Intraclass correlation coefficient, *Mean bias p<0.05, **Mean bias p<0.01, ***Mean bias p<0.001. N=Newtons, ms^{-1}= Meter per seconds, W=Watts, Qualitative inferences are trivial (<0.20), small (0.20 to <0.60), moderate (0.60 to <1.20), large (1.20 to <2.00) and extremely large (>2.00): possibly, 25 to <75; likely, 75 to <97.5%; very likely, 97.5 to <99.5%; most likely, >99.5. F_0: Theoretical maximal force in newtons, V_0: Theoretical maximal velocity in meters per second, P_{max}: Theoretical maximal power in watts, S_{FV}: slope of the force-velocity profile.*

Table 2 Predicted bias from repetitions performed with maximal and submaximal efforts for all devices combined

			Predicted bias at low values (20% of sample range)			Predicted bias at moderate values (50% of sample range)			Predicted bias at high values (80% of sample range)		
			Mean bias (±CL)	Mean bias % (±CL)	Standardized difference (±CL)	Mean bias (±CL)	Mean bias % (±CL)	Standardized difference (±CL)	Mean bias (±CL)	Mean bias % (±CL)	Standardized difference (±CL)
Maximal effort	Average	Force (N)	-139.7 ± 7.5***	-9.2 ± 0.5	-0.18 ± 0.01	-111 ± 7.6***	-7.32 ± 0.5	-0.14 ± 0.01	-82.2 ± 14***	-5.42 ± 0.92	-0.11 ± 0.02
		Velocity (ms^{-1})	0.03 ± 0.003***	2.9 ± 0.3	0.05 ± 0.01	0.04 ± 0.002***	4.85 ± 0.21	0.09 ± 0.00	0.06 ± 0.003***	6.8 ± 0.37	0.13 ± 0.01
		Power (W)	-122.5 ± 18***	-10.5 ± 1.5	-0.19 ± 0.03	-156.1 ± 15.5***	-13.4 ± 1.33	-0.25 ± 0.02	-189.6 ± 28***	-16.28 ± 2.41	-0.3 ± 0.04
	Peak	Force (N)	-72.6 ± 10.4***	-4.0 ± 0.6	-0.08 ± 0.01	-40.7 ± 9.6***	-2.27 ± 0.53	-0.05 ± 0.01	-8.9 ± 17.3	-0.5 ± 0.97	-0.01 ± 0.02
		Velocity (ms^{-1})	0.02 ± 0.005***	1.5 ± 0.4	0.03 ± 0.01	0.02 ± 0.003***	2.18 ± 0.30	0.04 ± 0.01	0.03 ± 0.006***	2.85 ± 0.51	0.05 ± 0.01
		Power (W)	-352.4 ± 43.4***	-23.2 ± 2.9	-0.44 ± 0.05	-413.7 ± 36.7***	-27.22 ± 2.42	-0.51 ± 0.05	-475.1 ± 66***	-31.25 ± 4.38	-0.59 ± 0.08
Submaximal effort	Average	Force (N)	-40.7 ± 5.9***	-2.7 ± 0.4	-0.05 ± 0.01	-49.8 ± 4.6***	-3.28 ± 0.30	-0.06 ± 0.01	-58.8 ± 8.2***	-3.88 ± 0.54	-0.08 ± 0.01
		Velocity (ms^{-1})	0.02 ± 0.001***	2.57 ± 0.10	0.05 ± 0.00	0.04 ± 0.001***	4.4 ± 0.14	0.08 ± 0.00	0.06 ± 0.003***	6.22 ± 0.29	0.12 ± 0.01
		Power (W)	14.9 ± 4.2***	1.3 ± 0.4	0.02 ± 0.01	-6.4 ± 4.8**	-0.55 ± 0.41	-0.01 ± 0.01	-27.6 ± 9.8***	-2.37 ± 0.84	-0.04 ± 0.02
	Peak	Force (N)	78.9 ± 7.7***	4.4 ± 0.4	0.09 ± 0.01	44.1 ± 5.5***	2.46 ± 0.31	0.05 ± 0.01	9.3 ± 9.5	0.52 ± 0.53	0.01 ± 0.01
		Velocity (ms^{-1})	0.02 ± 0.001***	1.97 ± 0.10	0.04 ± 0.00	0.04 ± 0.003***	3.25 ± 0.23	0.06 ± 0.00	0.05 ± 0.005***	4.52 ± 0.47	0.08 ± 0.01
		Power (W)	-7.1 ± 8.2	-0.5 ± 0.5	-0.01 ± 0.01	-64.2 ± 10***	-4.22 ± 0.65	-0.08 ± 0.01	-121.2 ± 19***	-7.97 ± 1.28	-0.15 ± 0.02

*Submaximal protocols = 467 repetition (n=14) and maximal protocol = 530 repetitions (n=11). N=Newtons, ms^{-1}= Meter per seconds, W=Watts, CL: 95% Compatibility limits. *Mean bias p<0.05, **Mean bias p<0.01, ***Mean bias p<0.001.*