



Validity and within-session reliability of the Exerfly system: A comparison of motorised and non-motorised flywheel squats

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Abstract

This study examined the concurrent validity and within-session reliability of the Exerfly flywheel application. Twelve resistance-trained men completed repeated flywheel back-squat sessions across six inertial loads (0.025–0.15 kg·m²) using motorised and non-motorised modes. Mean and peak concentric and eccentric force and velocity were recorded simultaneously using the Exerfly rotary encoder system and a MuscleLab unit. Concurrent validity was assessed using Bland-Altman limits of agreement (LoA) and concordance correlation coefficients (CCC) while accounting for repeated measures. Proportional bias was examined where present. Within-session inter-set reliability was evaluated using ICC(2,1), CV, and SEM. Mean concentric velocity demonstrated the highest agreement between systems, with small, non-significant bias and very large concordance in both non-motorised (0.04 m/s [95% CI: –0.01, 0.08], CCC = 0.80) and motorised (0.01 m/s [95% CI: –0.02, 0.04], CCC = 0.86) conditions. Motorised mean eccentric force also showed trivial bias and nearly perfect concordance (–5 N [95% CI: –23, 13], CCC = 0.94), although with wide LoA. In contrast, mean eccentric velocity and all peak variables exhibited systematic bias and lower concordance, with proportional bias evident particularly at higher forces and velocities. Despite this, both systems demonstrated good-to-excellent inter-set reliability across variables (ICC range: 0.64–0.99; CV%: 1.13–10.16). Agreement between systems was limited for interchangeable use across most mechanical outputs. Mean concentric velocity and motorised mean eccentric force showed the most acceptable agreement, whereas the remaining force and velocity measures demonstrated substantial bias. Nonetheless, both systems exhibited strong reliability, supporting their independent use for monitoring flywheel training performance.

Protocol registration: The original protocol was prospectively registered at the Open Science Framework (<https://osf.io/acpvs>).

Keywords

Concentric velocity, eccentric overload, inertial load, resistance training, rotary encoder

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Introduction

Over the past two decades, flywheel resistance training has gained significant attention in athletic environments due to its unique ability to provide eccentric overload.¹ Flywheel devices have been shown to improve strength, power, hypertrophy, jump performance, speed, and change of direction ability,^{2–7} as well as promote positive tendon adaptations.^{8,9} To maximise these benefits and minimise risks such as overtraining and injury,¹⁰ accurate quantification of flywheel training loads is essential. In the broader resistance training literature, metrics such as velocity and force are commonly used to prescribe training intensity and monitor performance adaptations.^{11,12} Consequently, valid and

reliable measurement systems are required to ensure that practitioners can precisely prescribe intensity and monitor training loads.

While the prescription and monitoring of those metrics are well established in traditional resistance training, their

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application to flywheel resistance training is less clearly defined. For example, load individualisation is recommended for flywheel training,¹³ yet few studies have investigated methods (e.g., velocity-based) for standardising and prescribing training intensity within a longitudinal study design.^{4,14–16} Generally, studies have used pre-allocated inertial load settings; while practical, this approach fails to account for individual differences, potentially leading to varied adaptational responses between participants. The complex nature of flywheel training, characterised by varying inertial settings, the integration of new motorised systems,¹⁷ and the manipulation of the athlete's intent, highlights the importance of accurately characterising the mechanical stimulus to understand its impact.

Until recently, flywheel research primarily relied on force plates, linear position transducers (LPT), video analysis, and strain gauges to quantify flywheel training intensity.¹⁸ Although these reference systems provide accurate measurements and valuable insights in laboratory settings, their data collection and processing demands are time-consuming and often impractical for daily use. An easy-to-use, Bluetooth-enabled load-monitoring application could accelerate load-individualisation sessions and make within-session data monitoring significantly more convenient. Accordingly, contemporary flywheel devices commonly use rotary encoders to track shaft rotation. These data are used to calculate angular velocity (ω) and acceleration (α), from which torque (T) and power (P) are subsequently estimated based on these known kinematic properties of the system.¹⁹ However, strength and conditioning practitioners typically interpret mechanical output using linear metrics, such as linear velocity (V), force (F), and power (P). Therefore, the accurate conversion of angular metrics into linear metrics is essential for assessing the force-velocity profile and total mechanical work performed during flywheel exercises. Furthermore, the validity and reliability of these derived outcomes may be influenced by factors such as flywheel inertia and the specific operating mode (i.e., motorised vs non-motorised). Therefore, proper validation ensures that the mechanical characteristics of flywheel training across different inertial loads and flywheel modes can be meaningfully compared across different training settings and against traditional resistance training methods.

One manufacturer, Exerfly, has recently released a motorised device that can apply a customisable amount of eccentric overload using an electric motor, while also enabling real-time tracking of performance metrics such as velocity and force via the device application. However, the validity and within-session reliability of these mechanical outputs across different flywheel modes remain unclear. Therefore, this study aims to evaluate the validity and reliability of the Exerfly application compared with commonly used devices, including MuscleLab's LPT and strain gauge.

Materials and methods

Research design

A randomised, within-participant, crossover design with repeated measures was employed. Participants performed back squats on a flywheel device equipped with an inbuilt motor across various inertial loads and motorised/non-motorised modes. To evaluate concurrent validity, force and velocity were measured simultaneously via an LPT and a strain gauge (i.e., the reference system), as well as the in-built rotary system of the flywheel device. This study is part of a broader pre-registered project (osf.io/acpvs) investigating flywheel training monitoring and prescription across various overload conditions.

Participants

Twelve resistance-trained males (mean $\pm$ SD: age 26.5 ± 5.40 years; height 179.28 ± 7.56 cm; body mass 88.73 ± 12.14 kg; resistance training experience 7.63 ± 4.76 years; one-repetition maximum (1-RM) back squat/body mass ratio 1.70 ± 0.29) participated in the study. All participants reported their most recent single or multiple back squat loads in kilograms. Participants were free from injury and disease at the time of testing. The experimental procedures were approved by the Auckland University of Technology Ethics Committee (24/283), and all participants provided written informed consent prior to participation. While this research question was indicated as a secondary component of the pre-registered project, no a priori power analysis was performed for this element. Thus, this study is exploratory and prioritises quantifying agreement and associated uncertainty via mean bias and Limits of Agreement (LoA). Accordingly, interpretation focuses on whether the magnitude and precision of observed differences are likely to be practically meaningful for applied load prescription.

Data collection and procedure

All participants attended four sessions on separate days: one familiarisation session (no data collected), one reduced testing session (incorporating both motorised and non-motorised modes), and two full experimental sessions. The order of conditions for the two full experimental sessions (non-motorised or motorised) was randomly assigned for each participant using an online randomisation tool (<https://www.randomizer.org>).

During the full experimental sessions, following a standardised warm-up, participants performed 12 sets of six repetitions of flywheel squats. For each inertia level (0.025, 0.05, 0.075, 0.1, 0.125, and 0.15 kg·m²), they completed two sets of six repetitions in either the motorised or non-motorised mode. In the initial reduced familiarisation session, the inertial range was condensed to 0.05, 0.1, and

0.15 kg·m². In this session, participants performed the non-motorised sets first, followed by the motorised mode. All sets across all experimental sessions were separated by 4-min rest intervals. During all data collection sessions, knee range of motion was standardised between 90° and 170 ± 5°: participants began each repetition from a squat position with 90° of knee flexion, measured using a goniometer, and were instructed to reach 170–175° of knee extension at the concentric end range. During the eccentric phase, participants were instructed to stop the rope clamp at the same position on every repetition. Between sets, the MuscleLab system data were checked to ensure consistent displacement. From the second session onward, participants were instructed to perform each concentric action with maximal effort. During the eccentric phase, they were asked to delay abrupt braking until the final third of the movement.

The Exerfly flywheel (Exerfly Ultimate Version, Dynamic Fitness & Strength, Eau Claire, WI, USA) features a motorised eccentric boost that is triggered after the flywheel reaches three initial revolutions, ensuring a sufficient range of motion. During the late concentric phase, the system calculates rotational kinetic energy ($KE = \frac{1}{2}I\omega^2$) and engages the motor to accelerate the flywheel. This increases the total kinetic energy by a preselected boost percentage, ensuring that the energy entering the eccentric phase exceeds that generated concentrically, thereby providing repeatable eccentric overload. In the present study, the motorised mode was set to provide a 20% eccentric boost; this selection was based on preliminary piloting to ensure a meaningful eccentric overload. Experimental sessions were separated by ≥ 7 days.

Mean and peak force and velocity data were collected during both the concentric and eccentric phases of the flywheel half-back squat, which participants performed with arm placement self-selected according to individual shoulder and thoracic mobility. The MuscleLab (Ergotech Innovation AS, Stanhelle, Norway) system, consisting of an LPT (sampling rate: 200 Hz) and a strain gauge (sampling rate: 200 Hz), was used as the reference system measure. The strain gauge was attached in series between the flywheel squat harness and the flywheel rope, while the LPT was positioned on the participant's back using a wooden dowel aligned with the line of action (Figure 1). This placement was selected after pilot testing revealed that positioning the LPT near the strain gauge produced noisy data due to physical interference. A MuscleLab wired data synchronisation unit (DSU) was used to collect instantaneous raw force and velocity data. The concentric and eccentric phases were identified by positive and negative velocity values, respectively. Initial data analysis was performed in Microsoft Excel using PivotTable functions to calculate mean and peak force and velocity values for each repetition during both phases, across all inertia levels, exercise modes, and muscle actions. Simultaneously, force and velocity data were collected from the Exerfly via

Bluetooth connection with default settings, using an Android tablet (Samsung Galaxy S7 FE, Seoul, South Korea). The Exerfly Bluetooth application recorded rotary encoder-derived force and velocity data at a sampling rate of 1000 Hz. The primary outcome variables were mean and peak concentric and eccentric velocity and force. The 1st and 6th repetitions were excluded from all analyses to account for submaximal efforts at the start and end of the set. The first repetition also represents a mechanically distinct condition, as it requires overcoming zero momentum, resulting in lower velocity but higher impulse compared to subsequent repetitions.¹⁶

During data collection, the Exerfly device was using an early access software application and experienced intermittent Bluetooth disconnection (this issue has since been resolved). This instability resulted in missing data for some repetitions. Only paired data samples (i.e., repetitions with corresponding MuscleLab and Exerfly values) were included in the analysis. All MuscleLab data points and the corresponding missing Exerfly data points are provided in the supplementary file (<https://osf.io/acpvs>). Across all conditions, 13,824 repetitions were captured with MuscleLab, of which 12,506 were simultaneously recorded by the Exerfly system. This resulted in 1318 missing Exerfly data points (9.53% of the MuscleLab total). As data were lost at the repetition level, the concentric and eccentric phases were lost simultaneously for the same repetitions, meaning missingness was equivalent across phases. It is also worth noting that data points at the 0.05, 0.1, and 0.15 kg·m² inertial loads were greater in number than at the remaining loads (0.025, 0.075, and 0.125 kg·m²), as the former were also used during the second familiarisation session, resulting in additional repetitions at those loads. Although missing data points, the number of paired Exerfly and MuscleLab data points for each outcome variable, in each flywheel mode and phase, across inertial loads was quite substantial (≥772).

Statistical analysis

All analyses were conducted using R (Version 4.5.1; R Core Team, 2025) in RStudio (Version 2025.09.1 + 401; Posit Software, PBC, Boston, MA, USA), using the *SimplyAgree* package (version 0.2.1).²⁰ Specifically, concurrent validity was assessed by comparing the Exerfly Bluetooth application (data collected via the device's rotary encoder) against the MuscleLab strain gauge and LPT, which served as reference system measures, under different flywheel modes (motorised and non-motorised) and movement phases (concentric and eccentric). Inertial loads were not analysed separately, as the aim was to examine values derived from all levels combined for agreement analysis.

The agreement was evaluated using the Bland-Altman Limits of Agreement (LoA) at a 95% agreement level via the `agreement_limit()` function. Because the dataset

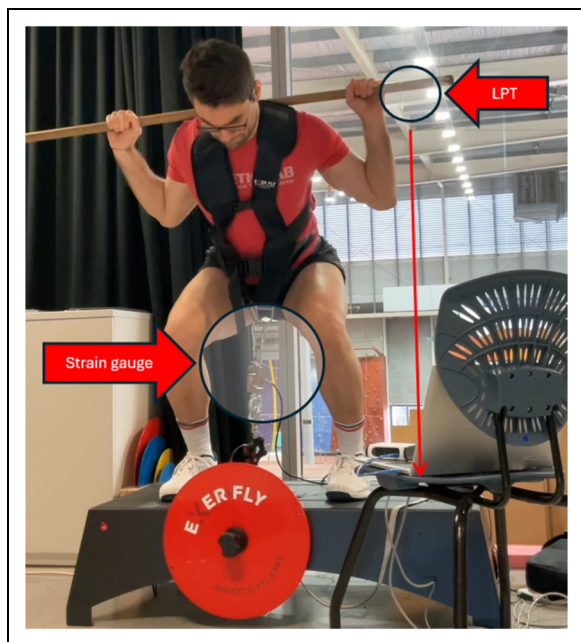


Figure 1. Locations of the strain gauge and LPT. This figure is representative only and was taken during an early pilot session; the experimental standardisations described in the text were not yet implemented. In the experimental setup, the LPT was positioned on the ground, off the flywheel platform, to align with its line of action.

included multiple repetitions per participant, the function incorporated a linear mixed model framework to account for the nested (within-participant) data structure and estimate variance components appropriately. Systematic bias was tested for statistical significance using the 95% confidence interval (CI) of the mean difference; bias was considered statistically significant if the CI did not include zero. Model diagnostics indicated the presence of proportional bias across all outcome variables, which, while minor practically for some variables (via plots), appeared meaningful for others. Therefore, the proportional bias analyses and adjusted values are reported in the supplementary material. Additionally, the Concordance Correlation Coefficient (CCC) was calculated using the *SimplyAgree*, *agree_nest()* function to assess relative agreement, interpreted as follows: 0.0–0.1 = trivial, 0.1–0.3 = small, 0.3–0.5 = moderate, 0.5–0.7 = large, 0.7–0.9 = very large, 0.9–1.0 = nearly perfect, and 1.0 = perfect correlation.²¹

For reliability, data were filtered to include only experimental sessions and averaged across repetitions for set-level data. Reliability was assessed separately for the Exerfly and MuscleLab devices to illustrate internal device reliability across the inertial loads of 0.05, 0.1, and 0.15 kg·m². Within-device intra-session reliability across sets was evaluated using a two-way random-effects, absolute-agreement intraclass correlation coefficient for a single measure [ICC(2,1)] with the following formula

$$ICC(2, 1) = \frac{(MS_B - MS_E)}{(MS_B + (n_j - 1) \cdot MS_E + n_j \cdot (MS_R - MS_E) \cdot n^{-1})}$$
, and ICC values were reported alongside 95% confidence intervals (CI).²⁰ Absolute reliability was quantified in an absolute term using the coefficient of variation²² with the following equation²⁰:

$$CV(\%) = \left(\frac{\sqrt{MSE}}{\bar{y}} \right) \times 100$$
. Variables with a CV of $\leq 10\%$ were classified as demonstrating acceptable absolute reliability.²² In addition, the standard error of measurement (SEM) was calculated to estimate the typical absolute measurement error in the original units (m/s or N) with the following equation: $SEM = \sqrt{MSE}$.^{20,23} ICC values were interpreted as proposed by Koo et al.,²⁴ with specific attention paid to the lower bound of the confidence interval, as follows: < 0.50 = poor, 0.50 – 0.75 = moderate, 0.75 – 0.90 = good, and > 0.90 = excellent reliability.

Results

Agreement results for peak and mean velocity and force variables across flywheel modes and movement phases are summarised in Table 1. Within-session inter-set ICC, CV, and SEM for concentric and eccentric mean and peak velocity and force at inertial loads of 0.05, 0.1, and 0.15 kg·m² in both non-motorised and motorised modes, separately for the MuscleLab and Exerfly devices, are presented in Tables 2–5. Bland-Altman limits of agreement (LoA) for all outcomes are illustrated in Figure 2–5. The expanded analysis of agreement, including Bland-Altman limits of agreement and proportional bias estimates, is available in Supplementary Table 1. Additionally, inter-set reliability scores based on the average of k measures [ICC (2, k)] are provided in Supplementary Tables 2–5. All supplementary documents were shared at <https://osf.io/acpvs>.

Agreement analysis

The highest agreement was found for mean concentric velocity measurements. In the non-motorised mode, mean concentric velocity bias was small and not statistically significant (0.04 m/s; 95% CI: -0.01 to 0.08 m/s), with relatively wide LoA (-0.16 to 0.23 m/s) and very large concordance (CCC = 0.80). In the motorised mode, mean concentric velocity did not show statistically significant bias (0.01 m/s; 95% CI: -0.02 to 0.04 m/s), narrower LoA (-0.14 to 0.16 m/s), and very large concordance (CCC = 0.86). Peak concentric velocities, as well as mean and peak eccentric velocities in both motorised and non-motorised modes, showed a significant bias and lower concordance (CCC = 0.31–0.69).

Mean concentric force in both modes and mean eccentric force measurements in the non-motorised mode also demonstrated very large to nearly perfect concordance (CCC = 0.80–0.93), although statistically significant bias was present. Notably, motorised eccentric mean force

Table 1. Agreement analysis between measurement methods for mean and peak velocity and force.

Variable	Flywheel mode	Phase	MuscleLab (mean $\pm$ SD)	Exerfly (mean $\pm$ SD)	Mean bias (95% CI)	Lower LoA	Upper LoA	LoA 95% CI	CCC (95% CI)
Mean Velocity (m/s)	Non-motorised	Concentric	0.82 $\pm$ 0.17	0.78 $\pm$ 0.15	0.04 (−0.01, 0.08)	−0.16	0.23	−0.20, 0.27	0.80 (0.78, 0.82)
		Eccentric	0.84 $\pm$ 0.19	1.01 $\pm$ 0.21	−0.17 (−0.22, −0.13)*	−0.38	0.03	−0.42, 0.07	0.62 (0.60, 0.65)
	Motorised	Concentric	0.74 $\pm$ 0.15	0.73 $\pm$ 0.14	0.01 (−0.02, 0.04)	−0.14	0.16	−0.17, 0.19	0.86 (0.85, 0.88)
		Eccentric	0.80 $\pm$ 0.16	1.02 $\pm$ 0.19	−0.22 (−0.25, −0.18)*	−0.41	−0.02	−0.45, 0.02	0.49 (0.46, 0.51)
Peak Velocity (m/s)	Non-motorised	Concentric	1.47 $\pm$ 0.32	1.27 $\pm$ 0.23	0.20 (0.12, 0.29)*	−0.17	0.58	−0.26, 0.67	0.61 (0.59, 0.63)
		Eccentric	1.72 $\pm$ 0.51	1.39 $\pm$ 0.25	0.32 (0.20, 0.44)*	−0.47	1.11	−0.57, 1.21	0.38 (0.35, 0.41)
	Motorised	Concentric	1.33 $\pm$ 0.26	1.20 $\pm$ 0.19	0.13 (0.07, 0.20)*	−0.16	0.42	−0.23, 0.50	0.69 (0.67, 0.71)
		Eccentric	1.73 $\pm$ 0.39	1.46 $\pm$ 0.20	0.26 (0.17, 0.35)*	−0.39	0.92	−0.47, 1.00	0.31 (0.28, 0.35)
Mean Force (N)	Non-motorised	Concentric	621 $\pm$ 209	552 $\pm$ 176	69 (50, 87)*	−35	173	−53, 190	0.91 (0.90, 0.91)
		Eccentric	539 $\pm$ 194	596 $\pm$ 211	−57 (−76, −38)*	−162	48	−181, 66	0.93 (0.92, 0.94)
	Motorised	Concentric	640 $\pm$ 198	558 $\pm$ 192	83 (40, 127)*	−112	279	−158, 325	0.80 (0.79, 0.82)
		Eccentric	658 $\pm$ 229	664 $\pm$ 246	−5 (−23, 13)	−172	163	−187, 178	0.94 (0.93, 0.94)
Peak Force (N)	Non-motorised	Concentric	1008 $\pm$ 299	891 $\pm$ 265	118 (85, 151)*	−110	346	−139, 375	0.84 (0.83, 0.86)
		Eccentric	1113 $\pm$ 371	1001 $\pm$ 323	112 (43, 181)*	−241	465	−308, 532	0.83 (0.81, 0.84)
	Motorised	Concentric	1025 $\pm$ 277	908 $\pm$ 310	119 (30, 207)*	−334	571	−421, 658	0.65 (0.62, 0.67)
		Eccentric	1303 $\pm$ 388	1076 $\pm$ 395	228 (173, 283)*	−188	644	−236, 692	0.73 (0.71, 0.75)

*Statistically significant bias. SD: standard deviation; CI: confidence interval; LoA: limits of agreement; CCC: concordance correlation coefficient. LoA 95% CI indicates the confidence interval bounds for the lower and upper LoA. Mean and SD values represent data pooled across all inertial loads (0.025–0.15 kg·m²) within each phase and flywheel mode. These pooled means differ methodologically from the bias and LoA values, which are subject-averaged (nested); as a result, small discrepancies (± 1 N or m/s) between the pooled means and the mean bias may occur due to unequal numbers of observations per subject.

Table 2. Within-session, inter-set reliability of mean velocity for MuscleLab and Exerfly devices, across mode and inertial settings for concentric and eccentric phases.

Device	Flywheel mode	Inertia (kg·m ²)	Phase	ICC (95% CI)	CV (%)	SEM (m/s)
MuscleLab	Non-motorised	0.05	Concentric	0.97 (0.91, 0.99)	3.19	0.03
		0.05	Eccentric	0.98 (0.94, 0.99)	3.01	0.03
		0.1	Concentric	0.95 (0.86, 0.98)	4.09	0.03
		0.1	Eccentric	0.88 (0.70, 0.96)	5.90	0.04
		0.15	Concentric	0.95 (0.86, 0.98)	3.81	0.03
		0.15	Eccentric	0.95 (0.87, 0.98)	3.85	0.03
Exerfly	Non-motorised	0.05	Concentric	0.90 (0.72, 0.97)	3.93	0.03
		0.05	Eccentric	0.93 (0.79, 0.98)	4.36	0.05
		0.1	Concentric	0.97 (0.91, 0.99)	2.70	0.02
		0.1	Eccentric	0.97 (0.92, 0.99)	3.08	0.03
		0.15	Concentric	0.98 (0.94, 1.00)	1.48	0.01
		0.15	Eccentric	0.99 (0.96, 0.99)	1.93	0.02
MuscleLab	Motorised	0.05	Concentric	0.86 (0.66, 0.95)	5.74	0.05
		0.05	Eccentric	0.92 (0.79, 0.97)	4.51	0.04
		0.1	Concentric	0.97 (0.92, 0.99)	2.56	0.02
		0.1	Eccentric	0.95 (0.87, 0.98)	3.28	0.02
		0.15	Concentric	0.97 (0.91, 0.99)	2.80	0.02
		0.15	Eccentric	0.90 (0.75, 0.96)	4.58	0.03
Exerfly	Motorised	0.05	Concentric	0.87 (0.65, 0.96)	4.22	0.04
		0.05	Eccentric	0.90 (0.72, 0.97)	4.37	0.05
		0.1	Concentric	0.93 (0.81, 0.97)	3.13	0.02
		0.1	Eccentric	0.93 (0.81, 0.97)	3.31	0.03
		0.15	Concentric	0.98 (0.93, 0.99)	2.02	0.01
		0.15	Eccentric	0.91 (0.70, 0.97)	3.99	0.04

Reliability scores are reported from experimental sessions only (motorised or non-motorised) and represent the single-measure absolute agreement across sets.

displayed a trivial and statistically non-significant bias (-5 N; 95% CI: -23 to 13 N) and nearly perfect concordance (CCC = 0.94), although with relatively wide LoA (-172 to 163 N). Peak concentric and eccentric force values across both modes showed a significant bias and large to very large concordance (CCC = 0.65 – 0.84).

Proportional bias

Several variables showed a degree of meaningful proportional bias (Supplementary Table 1). For non-motorised mean concentric velocity, at high velocity levels (1.25 m/s), the bias increased and became statistically significant (0.07 m/s, 95% CI: 0.03 , 0.12 m/s), whereas at lower velocity levels (0.52 m/s), the bias was smaller and non-significant (0.02 m/s, 95% CI: -0.03 , 0.06 m/s). Similarly, motorised mean eccentric force exhibited statistically significant bias at both low (153 N) and high (1326 N) force levels (35 N, 95% CI: 13 , 57 ; and -57 N, 95% CI: -81 , -32 , respectively).

After proportional bias adjustment, several individual data points showed a reduced systematic bias. These included: Peak concentric velocity in the motorised mode at low peak velocity level (0.79 m/s; bias: 0.02 m/s, 95% CI: -0.04 , 0.08), mean concentric force in the non-motorised mode at low mean force level (175 N; bias: 0.2

N, 95% CI: -14 , 15), mean concentric force in the motorised mode at high mean force level (1184 N; bias: -41 N, 95% CI: -101 , 19), and peak eccentric force in the non-motorised mode at low peak force level (284 N; bias: 57 N, 95% CI: -12 , 126). All other variables showed strong proportional bias.

Reliability analysis

The inter-set reliability for the MuscleLab and Exerfly devices was generally excellent (>0.90) or good (0.75 – 0.90) with only a few exceptions. The lowest lower bounds of the ICC confidence intervals were observed for MuscleLab peak velocity in the eccentric phase of the motorised flywheel mode across all inertial points (ICC lower bounds = 0.24 , 0.30 , and 0.44 , respectively), Exerfly mean force in the eccentric phase of the non-motorised mode at 0.05 kg·m² (ICC lower bound = 0.40), and Exerfly peak force in the concentric phase of the motorised mode at 0.05 kg·m² (ICC lower bound = 0.49).

Discussion

To our knowledge, this is the first study to evaluate the validity and inter-set reliability of the Exerfly system across different flywheel modes (motorised vs. non-motorised)

Table 3. Within-session, inter-set reliability of mean force for MuscleLab and Exerfly devices, across mode and inertial settings for concentric and eccentric phases.

Device	Flywheel mode	Inertia (kg·m ²)	Phase	ICC (95% CI)	CV (%)	SEM (N)
MuscleLab	Non-motorised	0.05	Concentric	0.93 (0.81, 0.97)	4.18	19.15
		0.05	Eccentric	0.89 (0.73, 0.96)	5.95	23.49
		0.1	Concentric	0.96 (0.89, 0.99)	3.88	28.34
		0.1	Eccentric	0.93 (0.83, 0.98)	5.66	34.55
		0.15	Concentric	0.99 (0.96, 1.00)	1.88	18.17
		0.15	Eccentric	0.97 (0.87, 0.99)	3.06	27.09
Exerfly	Non-motorised	0.05	Concentric	0.95 (0.85, 0.99)	3.25	13.42
		0.05	Eccentric	0.78 (0.40, 0.93)	10.16	45.25
		0.1	Concentric	0.95 (0.87, 0.98)	4.28	26.42
		0.1	Eccentric	0.96 (0.90, 0.99)	4.06	28.05
		0.15	Concentric	0.98 (0.93, 0.99)	2.69	22.55
		0.15	Eccentric	0.98 (0.90, 1.00)	2.32	24.54
MuscleLab	Motorised	0.05	Concentric	0.91 (0.75, 0.97)	6.18	35.66
		0.05	Eccentric	0.87 (0.69, 0.95)	6.91	33.50
		0.1	Concentric	0.99 (0.97, 1.00)	3.12	21.48
		0.1	Eccentric	0.90 (0.74, 0.96)	5.82	42.61
		0.15	Concentric	0.96 (0.87, 0.99)	4.08	35.47
		0.15	Eccentric	0.90 (0.75, 0.96)	5.00	43.21
Exerfly	Motorised	0.05	Concentric	0.89 (0.70, 0.96)	5.93	24.74
		0.05	Eccentric	0.94 (0.83, 0.98)	4.36	20.76
		0.1	Concentric	0.98 (0.93, 0.99)	3.07	18.80
		0.1	Eccentric	0.92 (0.79, 0.97)	5.15	37.17
		0.15	Concentric	0.96 (0.88, 0.99)	3.04	25.19
		0.15	Eccentric	0.97 (0.91, 0.99)	2.98	26.38

Reliability scores are reported from experimental sessions only (motorised or non-motorised) and represent the single-measure absolute agreement across sets.

and muscle actions against a reference system. The primary findings indicate that mean concentric velocity in both non-motorised and motorised modes (0.04 m/s [95% CI: -0.01, 0.08] and 0.01 m/s [95% CI: -0.02, 0.04] respectively) and mean eccentric force in the motorised mode (-5 N [95% CI: -23, 13]) showed small and statistically non-significant mean bias. In contrast, the mean concentric force in both modes, the mean eccentric force in the non-motorised mode, and all peak velocity and force variables demonstrated larger systematic and statistically significant bias. Across all outcomes, the wide limits of agreement (LoA) indicate substantial individual variability and random error, suggesting that the devices may produce meaningfully different absolute values despite small average biases in some outcome variables. Systematic bias differed across levels for some variables after adjusting for proportional bias. Nevertheless, both systems demonstrated good-to-excellent internal reliability with a few exceptions (point estimates ranged from ICC = 0.64 to 0.99, CV% = 1.13–10.16).

The agreement in mean concentric velocity and mean eccentric force in the motorised mode is particularly noteworthy for practitioners. Since training prescription usually relies on velocity ranges rather than discrete points,⁴ the small bias observed suggests that intensity zones remain stable across devices. However, proportional bias analysis revealed that the accuracy for the mean non-motorised

concentric velocity was higher between the devices at slower speeds. Similarly, mean eccentric force values in the motorised mode showed almost no disparity between devices at an average level (moderate force levels). However, proportional bias analysis revealed that the discrepancy increased at the extreme ends of the force spectrum (low and high force levels). Taken together, these patterns indicate that the two devices produce more comparable outputs when movement is controlled and at moderate force levels. Despite small mean biases, the wide LoA suggests that absolute values vary considerably, which may stem from inconsistent movement quality during some repetitions. Anecdotally, we observed that when movement patterns were smoother, the agreement became more stable. Although speculative, this aligns with research suggesting that familiarisation influences mechanical outputs^{25–27}; novel flywheel stimuli may have generated unusual kinematic and kinetic changes, especially during the familiarisation session, contributing to random differences despite the small average bias. Additional mechanism, such as fatigue, may have influenced the bias results, although the extent of its impact remains unknown. The present study used relatively fewer sets compared to a previous study,²⁸ however, the 12 sets performed in the current study still represent a high volume for a single exercise within a session.

Table 4. Within-session, inter-set reliability of peak velocity for MuscleLab and Exerfly Devices, across mode and inertial settings for concentric and eccentric phases.

Device	Flywheel mode	Inertia (kg·m ²)	Phase	ICC (95% CI)	CV (%)	SEM (m/s)
MuscleLab	Non-motorised	0.05	Concentric	0.92 (0.74, 0.98)	3.21	0.04
		0.05	Eccentric	0.87 (0.65, 0.96)	3.82	0.06
		0.1	Concentric	0.99 (0.97, 1.00)	1.17	0.01
		0.1	Eccentric	0.85 (0.63, 0.95)	2.89	0.04
		0.15	Concentric	0.98 (0.93, 0.99)	1.47	0.02
Exerfly	Non-motorised	0.15	Eccentric	0.91 (0.77, 0.97)	3.28	0.04
		0.05	Concentric	0.96 (0.88, 0.99)	2.25	0.03
		0.05	Eccentric	0.91 (0.74, 0.97)	4.14	0.06
		0.1	Concentric	0.98 (0.96, 0.99)	1.65	0.02
		0.1	Eccentric	0.97 (0.93, 0.99)	2.65	0.03
MuscleLab	Motorised	0.15	Concentric	0.99 (0.98, 1.00)	1.13	0.01
		0.05	Concentric	0.93 (0.81, 0.97)	3.93	0.06
		0.05	Eccentric	0.64 (0.24, 0.86)	7.93	0.16
		0.1	Concentric	0.92 (0.74, 0.97)	3.92	0.06
		0.1	Eccentric	0.68 (0.30, 0.87)	7.18	0.11
Exerfly	Motorised	0.15	Concentric	0.93 (0.83, 0.98)	3.99	0.05
		0.15	Eccentric	0.75 (0.44, 0.90)	9.31	0.15
		0.05	Concentric	0.98 (0.95, 0.99)	2.59	0.04
		0.05	Eccentric	0.84 (0.62, 0.94)	9.67	0.19
		0.1	Concentric	0.89 (0.73, 0.96)	5.70	0.08
		0.1	Eccentric	0.79 (0.52, 0.92)	7.98	0.12
		0.15	Concentric	0.97 (0.92, 0.99)	2.93	0.04
		0.15	Eccentric	0.89 (0.71, 0.96)	5.85	0.08

Reliability scores are reported from experimental sessions only (motorised or non-motorised) and represent the single-measure absolute agreement across sets.

Table 5. Within-session, inter-set reliability of peak force for MuscleLab and Exerfly Devices, across mode and inertial settings for concentric and eccentric phases.

Device	Flywheel mode	Inertia (kg·m ²)	Phase	ICC (95% CI)	CV (%)	SEM (N)
MuscleLab	Non-motorised	0.05	Concentric	0.95 (0.85, 0.98)	4.06	26.04
		0.05	Eccentric	0.96 (0.87, 0.99)	4.11	32.58
		0.1	Concentric	0.96 (0.91, 0.99)	3.00	30.91
		0.1	Eccentric	0.91 (0.78, 0.97)	4.73	57.31
		0.15	Concentric	0.91 (0.76, 0.97)	4.75	59.54
Exerfly	Non-motorised	0.15	Eccentric	0.93 (0.80, 0.97)	4.60	66.61
		0.05	Concentric	0.88 (0.64, 0.96)	5.52	36.99
		0.05	Eccentric	0.94 (0.82, 0.98)	5.70	46.12
		0.1	Concentric	0.91 (0.76, 0.97)	4.32	43.54
		0.1	Eccentric	0.95 (0.87, 0.98)	4.68	52.80
MuscleLab	Motorised	0.15	Concentric	0.97 (0.91, 0.99)	2.88	34.24
		0.15	Eccentric	0.99 (0.97, 1.00)	2.08	25.97
		0.05	Concentric	0.86 (0.62, 0.95)	5.75	56.36
		0.05	Eccentric	0.89 (0.72, 0.96)	6.01	62.02
		0.1	Concentric	0.93 (0.82, 0.97)	6.03	64.94
Exerfly	Motorised	0.1	Eccentric	0.89 (0.72, 0.96)	6.07	86.06
		0.15	Concentric	0.87 (0.65, 0.95)	6.08	80.78
		0.15	Eccentric	0.91 (0.77, 0.97)	5.84	91.72
		0.05	Concentric	0.78 (0.49, 0.91)	7.00	55.64
		0.05	Eccentric	0.89 (0.71, 0.96)	8.94	81.39
		0.1	Concentric	0.88 (0.64, 0.96)	4.39	56.09
		0.1	Eccentric	0.92 (0.73, 0.97)	6.36	89.48
		0.15	Concentric	0.95 (0.87, 0.98)	3.61	48.11
		0.15	Eccentric	0.96 (0.90, 0.99)	4.48	58.03

Reliability scores are reported from experimental sessions only (motorised or non-motorised) and represent the single-measure absolute agreement across sets.

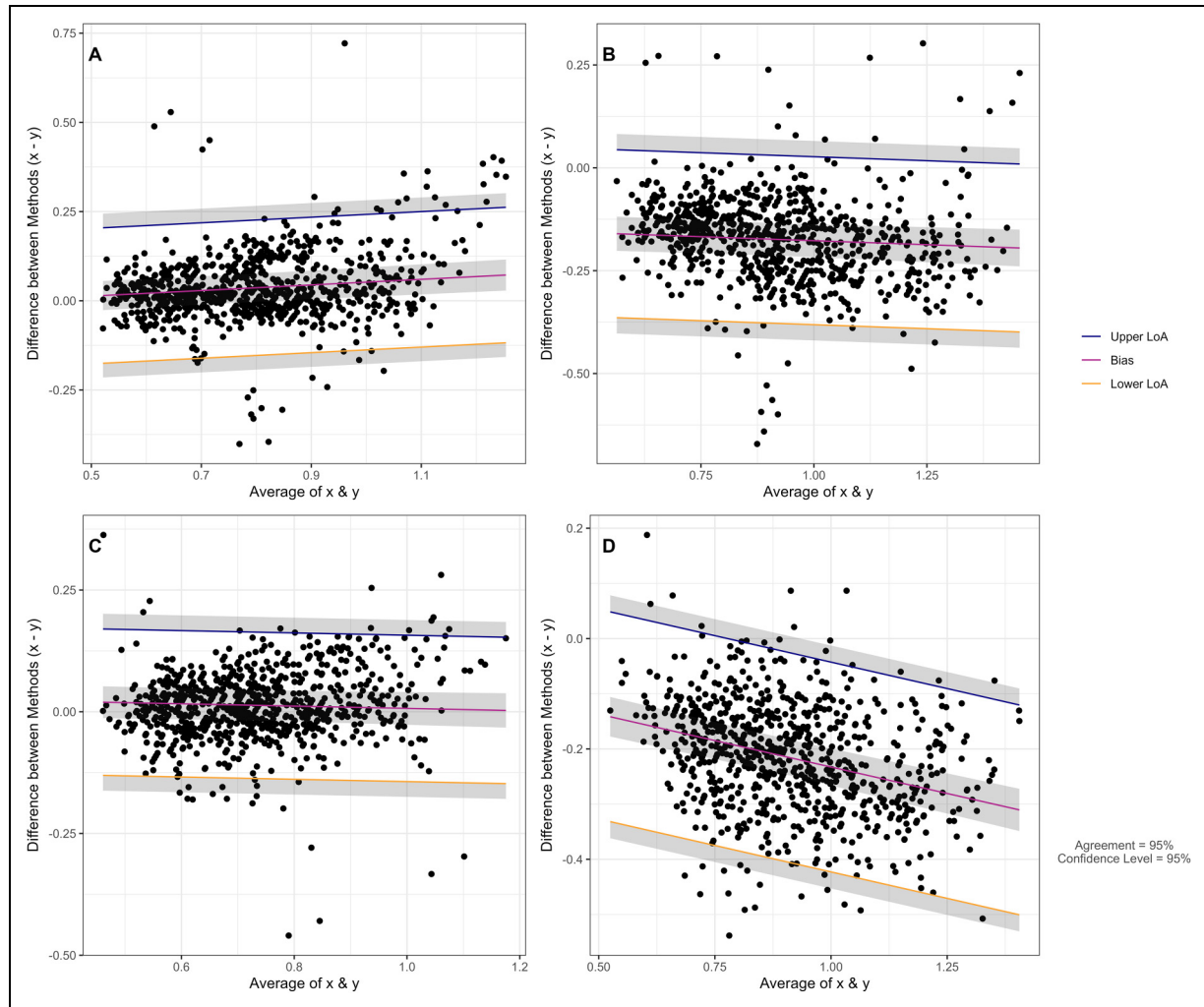


Figure 2. Bland-Altman plots representing the agreement between MuscleLab (x) and Exerfly (y) for mean velocity. (A) Non-motorised concentric phase; (B) Non-motorised eccentric phase; (C) Motorised concentric phase; (D) Motorised eccentric phase. The solid lines represent the proportional bias and 95% Limits of Agreement (LoA), with shaded areas indicating 95% confidence intervals.

Although participants were resistance-trained and intra-set repetitions were relatively low, fatigue may still have influenced the results by affecting movement kinematics and kinetics. Therefore, its effect may not be fully eliminated.

In contrast, mean eccentric velocity and all peak velocity outcomes demonstrated larger biases and lower concordance, indicating poor agreement between devices. Similarly, mean concentric and eccentric force in both non-motorised and motorised modes showed poor agreement despite exhibiting very large to nearly perfect concordance. Although proportional bias analyses showed reduced systematic biases for some of these variables, suggesting improvements at certain velocity or force levels, the wide LoA still indicates substantial random error and variability. Thus, even if some of these outcomes may appear usable for training or research purposes under specific conditions, the magnitude of variability means that interchangeable use

remains limited. Interchanging these variables across devices could result in assignment to different intensity zones and may lead to divergent training adaptations, suggesting these discrepancies carry practical significance. For example, the Exerfly system meaningfully overestimated mean eccentric velocity in both non-motorised and motorised modes (-0.17 m/s and -0.22 m/s, respectively). This overestimation could lead practitioners to erroneously conclude that users are achieving greater eccentric overload than is actually occurring. These findings raise an important conceptual question for flywheel practitioners: ‘Does a higher measured eccentric shaft velocity truly represent the eccentric overload experienced during the movement?’ This concern is not unique to the Exerfly device; rather, it reflects broader mechanical constraints across all flywheel systems that derive kinematic and kinetic variables from rotary encoders attached to the shaft.²⁹ The same challenge

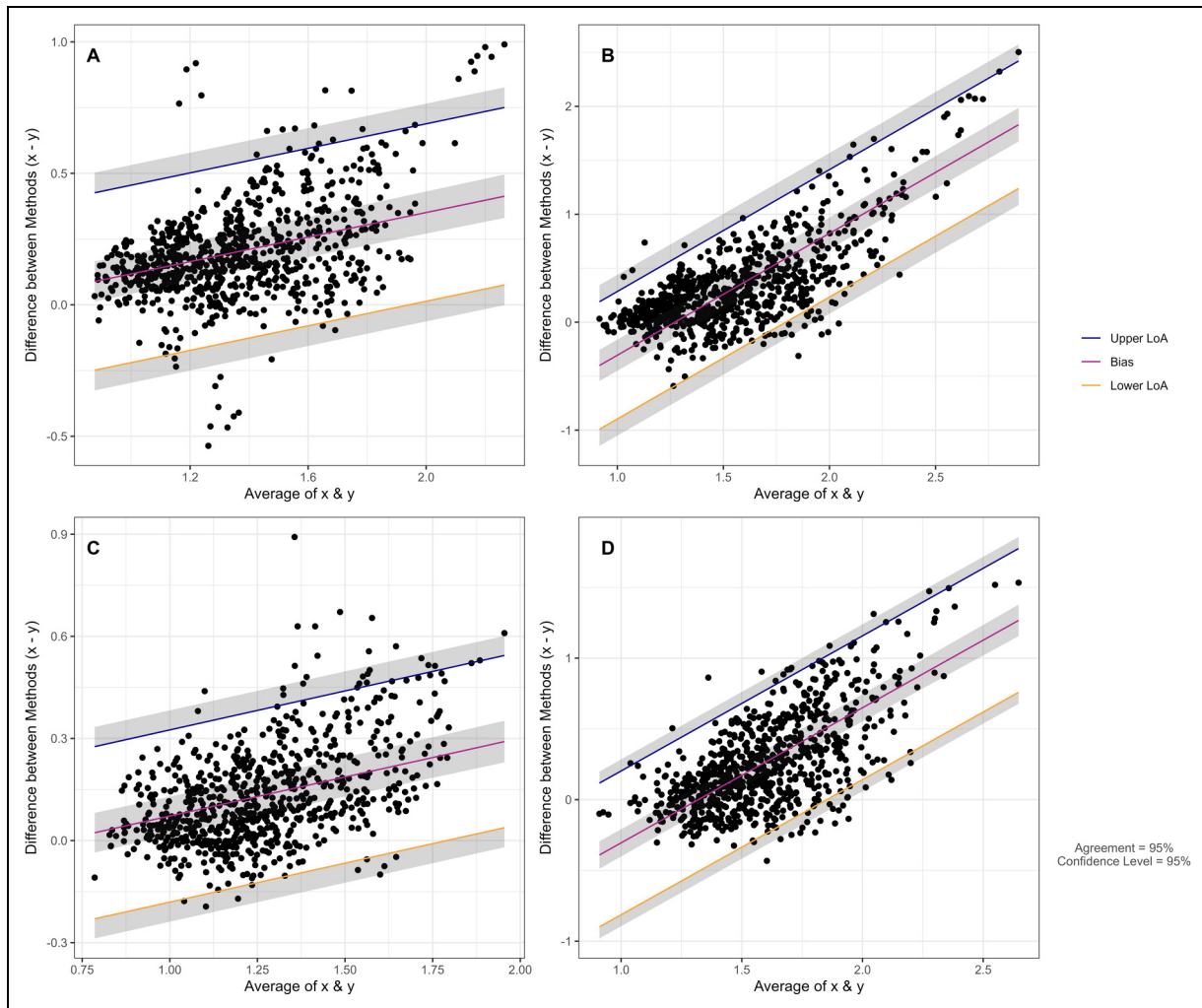


Figure 3. Bland-Altman plots representing the agreement between MuscleLab (x) and Exerfly (y) for peak velocity. (A) Non-motorised concentric phase; (B) Non-motorised eccentric phase; (C) Motorised concentric phase; (D) Motorised eccentric phase. The solid lines represent the proportional bias and 95% Limits of Agreement (LoA), with shaded areas indicating 95% confidence intervals.

applies to force variables when comparing data derived from rotary encoders versus strain gauges, as demonstrated in our study.

Problems associated with rotary encoders stem from inaccuracies in measuring kinetic and kinematic data.³⁰ These devices inherently function as low-pass filters, smoothing out high-frequency velocity oscillations typical of explosive movements.³⁰ In the present study, these limitations were evident across nearly all outcome variables, with the notable exception of mean concentric velocity. Interestingly, previous research has reported that signal smoothing becomes more problematic at higher inertial ranges.³⁰ Conversely, we observed greater accuracy and reduced mean bias as velocity decreased. Research indicates that observed differences between systems regarding concentric and eccentric phases may also be due to the tension of the flywheel tether.³¹ While tether tension is

constant across concentric phases, a slack tether may lead to estimation differences in the eccentric phase, particularly at lower inertia and high-velocity settings.³¹ Because the shaft continues spinning during the transition between phases, a faster transition is required²²; therefore, an inability to perform smooth transitions may explain the overestimation of values in the eccentric phase (mean velocity). Our study's proportional bias analyses support this trend that mean and peak eccentric variables showed increased overestimations or underestimations in higher movement velocities. One study suggested a solution to overcome these differences might be to leave the flywheel tether slightly loose in lower inertial settings²²; however, this hypothesis remains to be tested. As aforementioned, limitations may not be fully related to the rotary encoder itself, but also to participant characteristics. Perhaps a less velocity-trained (ballistic) population may exhibit poorer transitions from

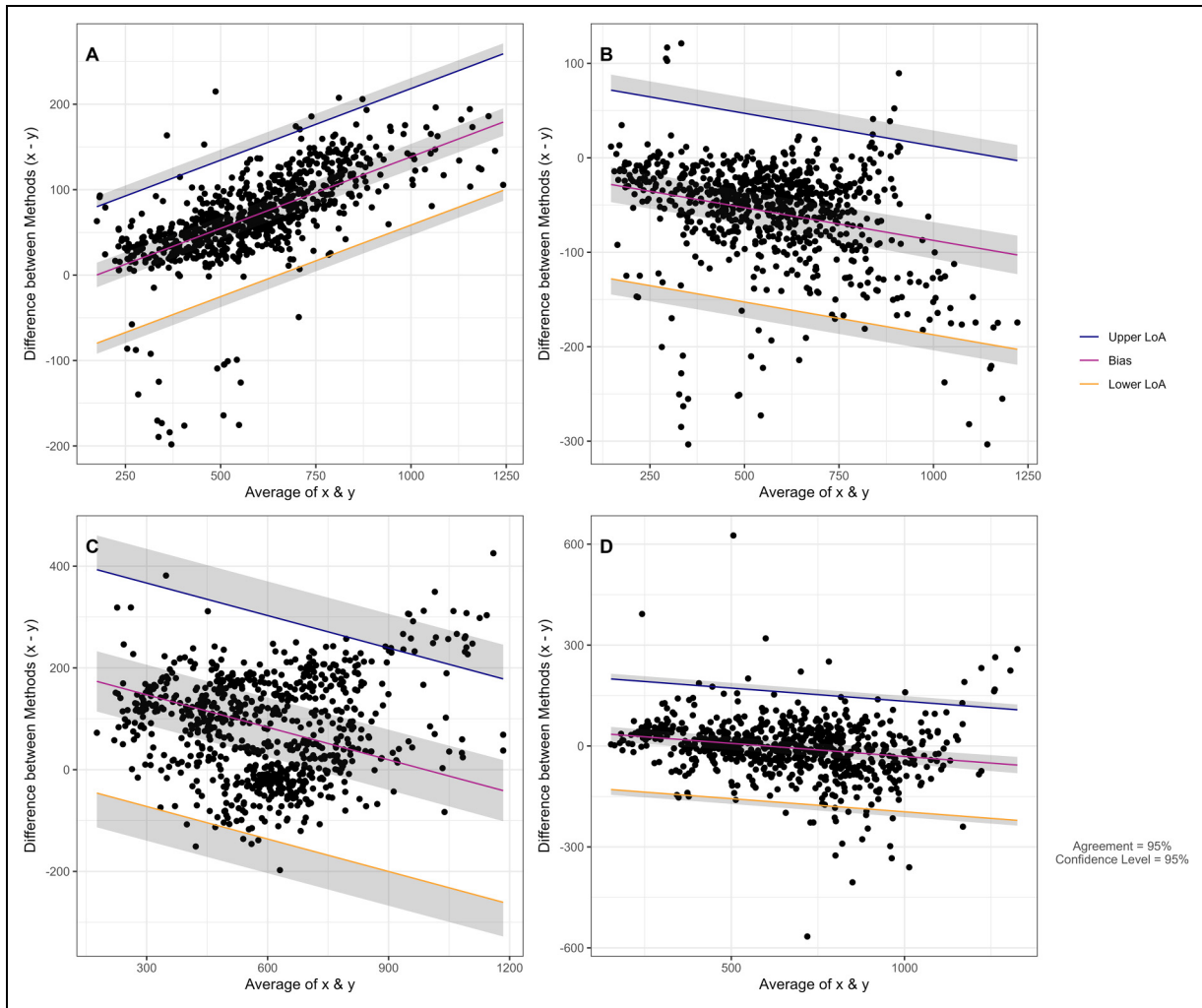


Figure 4. Bland-Altman plots representing the agreement between MuscleLab (x) and Exerfly (y) for mean force. (A) Non-motorised concentric phase; (B) Non-motorised eccentric phase; (C) Motorised concentric phase; (D) Motorised eccentric phase. The solid lines represent the proportional bias and 95% Limits of Agreement (LoA), with shaded areas indicating 95% confidence intervals.

the concentric to the eccentric phase, meaning the tether becomes loose momentarily and spools freely during the transition, which makes it more difficult for algorithms to accurately detect kinematic and kinetic changes at lower inertial settings. This may occur because, at lower inertia settings, the high velocity of the movement provides insufficient time for participants to perceive the transition between the concentric and eccentric phases. This difficulty in determining correct transition timing may lead to discrepancies between devices. Therefore, the differences between systems appear to result from a combination of rotary encoder limitations, participants' strength characteristics, and levels of familiarity with the flywheel. Consequently, the accuracy of the mechanical output relies heavily on the precision of the manufacturer's proprietary algorithms at this stage.

Regarding reliability, both systems indicated strong internal consistency. The good-to-excellent within-session

ICC, acceptable CV, and low measurement error were largely consistent across the different conditions.^{10,28,30} However, some exceptions were observed predominantly at lower inertial loads and eccentric phases, which can likely be attributed to several factors. For instance, participants were familiarised with the device, but less habitually trained using flywheels—notably at higher velocities. The latter may have limited their ability to coordinate movements at low inertial settings and, accordingly, may explain the lower reliability (and potentially some degree of proportional bias). This may be attributed to the unique nature of transitioning between phases at high velocities (notably concentric to eccentric phases), and generally lower movement smoothness than more familiar or specifically trained cohorts. Similarly, closely related to participants' familiarisation status, variability in the eccentric phase, potentially influenced by technique execution, may have reduced reliability values. Fatigue could also be considered as a

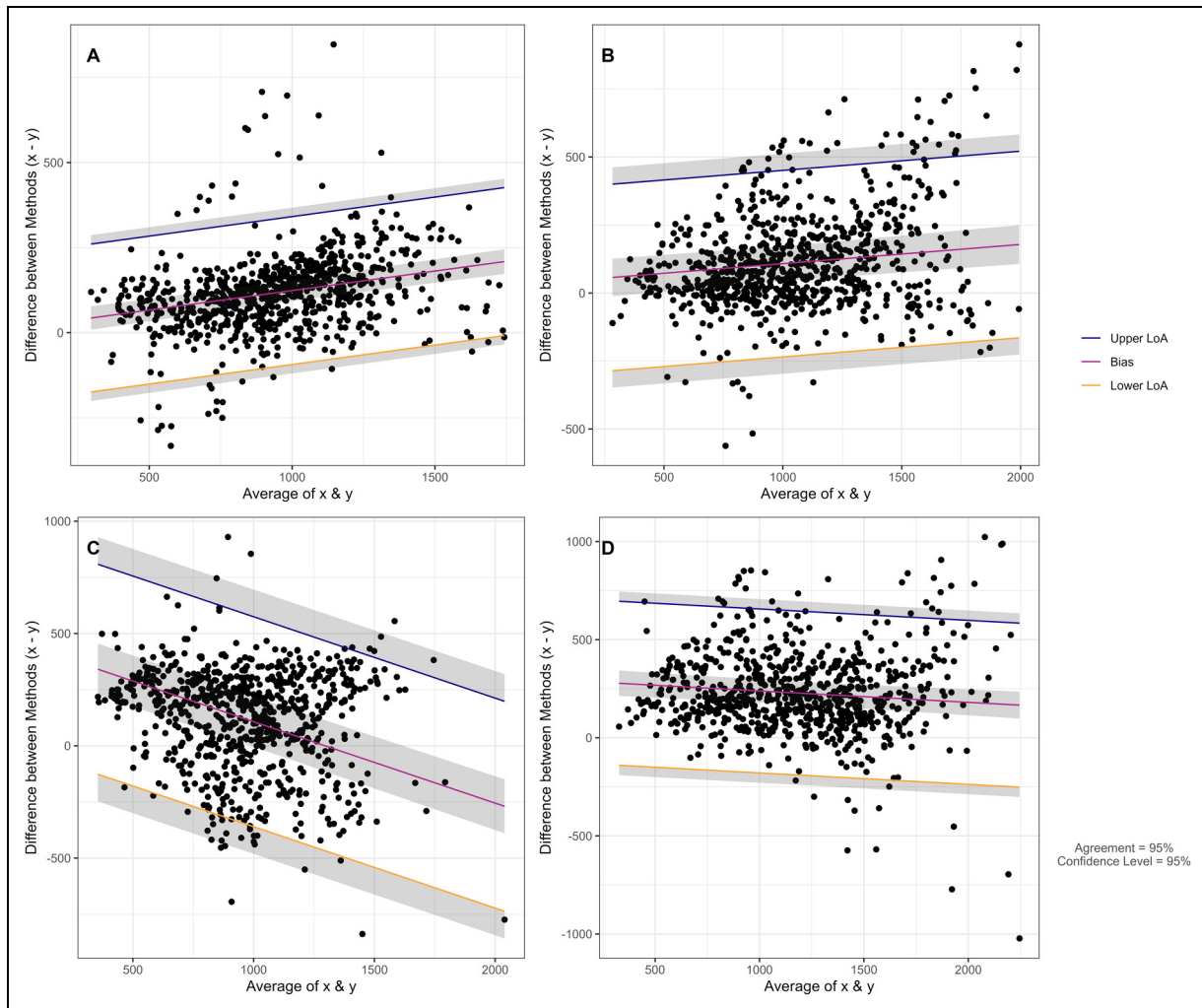


Figure 5. Bland-Altman plots representing the agreement between MuscleLab (x) and Exerfly (y) for peak force. (A) Non-motorised concentric phase; (B) Non-motorised eccentric phase; (C) Motorised concentric phase; (D) Motorised eccentric phase. The solid lines represent the proportional bias and 95% Limits of Agreement (LoA), with shaded areas indicating 95% confidence intervals.

potential mechanism that would blend the reliability results; however, the increased absolute (CV% and SEM) and relative (ICC) reliability observed with higher loads suggests that its effect on reliability outcomes was likely minimal or none. As emphasised, familiarisation status may instead have made it more difficult for participants to produce consistent effort between sets. Nevertheless, despite some lack of agreement between devices, each demonstrated sufficient internal reliability to be used independently for monitoring training intensity and tracking changes over time.

Beyond the validity and reliability outcomes reported above, several practical considerations are relevant to users selecting between these systems. In terms of ease of use, the flywheel device software requires only Bluetooth connectivity to the flywheel, whereas reference system involves setting up a strain gauge and LPT, which takes more time. Further, the system is more costly, given the involved components must be purchased separately. Moreover, the

reference system requires manual processing of the raw force and velocity data, whereas the flywheel software provides an automated summary of the metrics. Nonetheless, despite the added simplicity of the flywheel-integrated technology, during data collection for the study (which used an operational but early-release software), the flywheel software experienced Bluetooth connectivity issues that led to set-specific missing data (~9% across data, which appeared random). While we do not expect this data loss to have impacted our results, as we still obtained ≥ 772 paired data points for each outcome variable (e.g., mean velocity), flywheel mode (e.g., motorised), and phase (e.g., concentric), the practical implications of this data loss remain an important consideration. To our knowledge, the experienced connectivity issues have since been resolved, and future research, particularly as the software is updated and additional tracking variables are added, should retest these results. Taken together, these practical benefits suggest

that similarly equipped flywheels may be better suited to applied training environments, given their practicality, portability, and real-time feedback capabilities, whereas the reference system remains more appropriate for controlled, lab-based research; nonetheless, the flywheel software also demonstrates meaningful potential as a research tool in its own right, given its good-to-high within-device reliability. Finally, given the popularity and common use of mean concentric velocity over force and power variables for training prescription and tracking purposes, the flywheel software's performance with this metric makes it a solid option for these applications.

This study is not without limitations and considerations. First, intermittent Bluetooth connectivity resulted in missing data, which is a consideration for the practical validity of the system as mentioned above. Although agreement analyses were performed on the available data, practitioners should be aware that these results reflect only successfully captured repetitions. Second, while familiarised, participants may have exhibited poor kinematics due to the novelty of the flywheel stimulus at some repetitions. Although the extent of this influence is unknown, it may have affected results to some degree. Third, due to the high-volume nature of the experimental design, it may not be possible to fully eliminate the effects of fatigue on the results, particularly the mean bias results. Fourth, the strength-trained characteristics of the participants may have contributed to the observed differences, particularly under lower inertial load conditions, which require a quicker transition between concentric and eccentric phases. Future studies should utilise larger cohorts to strengthen statistical inferences and allocate more time to familiarising participants with the equipment. Furthermore, future research should investigate these validity results within other athletic populations and female cohorts to establish the broader generalisability and reliability of the scores.

Conclusion

Overall, the MuscleLab and Exerfly devices show limited agreement for interchangeable use across most variables. While mean concentric velocity and motorised mean eccentric force showed small biases, the consistently wide LoA demonstrates considerable random error. Therefore, practitioners should avoid using the devices interchangeably. If comparison is necessary, it should be restricted to those specific variables that demonstrated small biases. Nevertheless, both systems showed strong internal reliability and can be used independently to monitor training intensity and track performance over time.

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Ethics statement

Ethical approval for the experimental protocols was granted by the Auckland University of Technology Ethics Committee (Ref: 24/283), in accordance with the principles of the Declaration of Helsinki.

Consent

Participants provided written informed consent after being fully briefed on the study's objectives and any associated risks.

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Declaration of conflicting interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Equipment and software used in this study were provided by Exerfly under a collaboration agreement with the Auckland University of Technology. Exerfly had no role in study design, data collection, analysis, interpretation, manuscript preparation, or the decision to publish. Technical clarifications regarding the equipment were provided upon request by current and former Exerfly employees. The authors declare no personal and financial conflicts of interest, and no author is affiliated with Exerfly.

Data availability statement

Data and code for this study will be made available at osf.io/acpvs upon publication.

Supplemental material

Supplemental material for this article is available online.

Protocol registration

The protocol was prospectively registered at the Open Science Framework: osf.io/acpvs.

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