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Analyzing Force-Time Curves: Comparison of Commercially Available Automated Software and Custom MATLAB Analyses

Justin J. Merrigan,[1] Jason D. Stone,[1,2,3] Scott M. Galster,[4] and Joshua A. Hagen[1]

[1]Human Performance Collaborative, Office of Research, The Ohio State University, Columbus, Ohio; [2]College of Physical Activity and Sport Sciences, West Virginia University, Morgantown, West Virginia; [3]Athletics Department, West Virginia University, Morgantown, West Virginia; and [4]Mile Two, Dayton, Ohio

Abstract

Merrigan, JJ, Stone, JD, Galster, SM, and Hagen, JA. Analyzing force-time curves: Comparison of commercially available automated software and custom MATLAB analyses. *J Strength Cond Res* XX(X): 000–000, 2022—With the growing prevalence of commercial force plate solutions providing automated force-time curve analysis, it is critical to understand the level of agreement across techniques. Thus, this study directly compared commercial and custom software analyses across force-time curves. Twenty-four male and female subjects completed 6 trials of countermovement, squat, and drop jumps, and isometric mid-thigh pulls on the same force plate. Vertical ground reaction forces were analyzed by automated software from Vald Performance, Hawkin Dynamics, and custom MATLAB scripts. Trials were visually assessed to verify proper landmark identifications. Systematic and proportional bias among analyses were compared via least products regressions, Bland-Altman plots, and percent error. Hawkin Dynamics had subtle differences in analysis procedures and demonstrated low percent errors across all tests (<3% error), despite demonstrating systematic and proportional bias for several metrics. ForceDecks demonstrated larger percent differences and greater biases for several metrics. These errors likely result from different identification of movement initiation, system weight, and integration techniques, which causes error to subsequent landmark identifications (e.g., braking/propulsive phases) and respective force-time metrics. Many metrics were in agreement between devices, such as isometric mid-thigh pull peak force consistently within 1 N across analyses, but some metrics are difficult and incomparable across software analyses (i.e., rate of force development). Overall, many metrics were in agreement across each commercial software and custom MATLAB analyses after visually confirming landmarks. However, because of inconsistencies, it is important to only compare metrics that are in agreement across software analyses when absolutely necessary.

Key Words: Hawkin Dynamics, ForceDecks, countermovement jump, drop jump, isometric mid-thigh pull, force plate

Introduction

Human performance scientists and practitioners routinely assess maximal muscular strength and power capabilities (26) to determine relative levels of preparedness to perform (e.g., occupational or sporting tasks) or neuromuscular fatigue and overuse injury risk (1,34). Force-time curves (i.e., time domain force data) from vertical ground reaction forces (vGRFs) of various exercises (e.g., jumping and isometric tests) are used to evaluate and monitor neuromuscular performances (1,5,46) because they are relatively simple to administer, time efficient, low injury risk, and reliable under appropriate testing procedures (3,4,6,32,34). Countermovement jump testing demonstrates content and face validity according to associations with occupational (i.e., military) and sport performances (22,25,37), power output (45), resiliency to fatigue (18,42,46), and injury risk (38). Additional assessments include isometric testing (i.e., no physical movement; isometric mid-thigh pull [IMTP]), which correlates with dynamic strength (2,8), the drop jump, which identifies an individual's ability to land appropriately and explosively reaccelerate under various conditions (28,30), and the squat jump, which removes all eccentric actions to isolate power production capabilities without support from elastic properties (19). Each aforementioned test demonstrates unique force-time curves typically grouped as follows: dynamic movements starting on force plates with no eccentric action or countermovement (e.g., squat jump), dynamic movements starting on the force plate with a countermovement (e.g., countermovement jump, plyometric push-up), dynamic movements starting off the force plate (e.g., drop jump or push-up), and isometric strength tests (e.g., IMTP, isometric bench). The differences in force-time curves require test-specific analyses to calculate the relevant time-domain metrics for each test.

Advances in technologies enable real-time automated analysis of force-time data via software processes with little to no human interactions, thereby allowing easier implementation of force plates by human performance practitioners. Although custom-built analysis allows complete awareness of the analytical processes, it requires months or years of training to obtain the skill set to efficiently use required software programs, such as Microsoft Excel (5), MATLAB (15), or R (40). Automated analyses are preferred, especially for high throughputs of data collection

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Address correspondence to Justin J. Merrigan, justin.merrigan@hsc.wvu.edu.

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because it permits more efficient handling of large-scale force-time data. These insights, such as real-time feedback and results, would otherwise be unavailable to human performance practitioners. Indeed, automated procedures provide increased speed of analytics and reduced human error potential. Consequently, practitioners are afforded additional time to focus on more important tasks stemming from force plate testing, such as making data-driven programmatic decisions. Despite the cost of common software licensing fees (~$1–3,000 USD per year), perhaps, the strongest argument against automated force-time data analysis is the potential for processing error and disagreement across analyses of the calculated metrics. Although the metrics are often well defined and may match across software analyses, the results are very dependent on the methodology in the software (i.e., rules for identifying the start and end of phases). Therefore, investigations are necessary to determine potential errors in automated procedures to maximize confidence levels in analysis and reporting efforts that inform decisions for individualized training and recovery.

Previous investigations determined force-time metrics' reliability (31) and ability to independently explain the variation in performances across individuals and conditions (i.e., the relative importance of a given force-time metric) (27,33,35). Additionally, force-time data validity is often determined from direct comparisons to criterion force plates using stable known masses (i.e., 40 kg) (11). Others have compared countermovement jumps performed separately on 2 force plates (7), but assessing different force-time curves would not control for individual variation in jumping performances. However, comparing force-time software analyses of the same force-time curves is required to identify metrics that are in agreement across devices. Discrepancies in outcome metrics among software analyses can stem from variations among force-time data processing and analysis (6,20,34), such as filtering and integration (i.e., the mathematical process of obtaining acceleration-, velocity-, and displacement-time data from raw force-time data) techniques that cause deviations in the same raw force-time curve (9,10,41), the determination of system weight (43), and thresholds for identifying the onset of movement landmark (9,13,39). Moreover, naming criteria (i.e., concentric vs. propulsive) and metric calculations (i.e., time bands vs. average or peak rate of force development [RFD]) (6,14) must be analogous for the comparison of force-time metrics across software analyses. By understanding which metrics are in agreement across commercially available analyses, practitioners will be able to draw more appropriate conclusions when making comparisons to other databases or historical data collected from another device. Thus, the purpose of this study was to determine the agreement among 2 commercially available force plate software to custom MATLAB analyses during the squat jump, countermovement jump, drop jump, and IMTP.

Methods

Experimental Approach to the Problem

To compare the force-time data analyses, subjects performed a series of power and strength testing on a single, portable, standardized force plate (Bertec Model FP4060-05-PT; Bertec Corp., Columbus, OH). For the purposes of comparing software analyses, squat jump, countermovement jump, drop jump, and IMTP force-time data from the Bertec force plate were processed by each commercially available software (ForceDecks and Hawkin Dynamics) and a custom MATLAB script to understand differences in metrics and calculation strategies.

To start the experimental session, subjects completed a supervised warm-up consisting of 5 minutes on a cycle ergometer and 5 minutes of dynamic stretches. After the warm-up, subjects were informed of each testing exercise protocol and were allowed up to 3 attempts to practice each exercise for brief familiarization. Then, subjects completed jump testing on the force plate, composed of 3 trials, separated by 15–30 seconds of rest, of various jump tests in the following order: squat jump, countermovement jump, and drop jump. After a 2- to 5-minute rest, the jump testing battery was repeated for a total of 6 trials per subject. Following a 5-minute rest period, subjects completed 2 sets of 3 IMTP trials, separated by 30–60 seconds of intraset rest and 2–5 minutes of interset rest.

Subjects

The study sample comprised male ($n = 16$; 24 ± 5 years of age; 4.6 ± 4.8 years of training) and female ($n = 8$; 22 ± 3 years of age; 1.9 ± 1.2 years of training) subjects that were recreationally active for at least 3 consecutive months and without a lower-body musculoskeletal injury within the past 6 months. Subjects were excluded if they presented with 1 or more items from the general health section of the American College of Sports Medicines' Physical Activity Readiness Questionnaire (2020 Par-Q+). Before initiating data collection, subjects were informed of the risks and benefits of the study and signed the institutionally approved informed consent document. All procedures were conducted according to the Declaration of Helsinki guidelines and approved by West Virginia University's Institutional Review Board (#2103262626).

Procedures

General Force Plate Preparation and Testing Protocols. Due to the potential error in force plate data across floor surfaces from vibrations, the spot on the hard rubber flooring (not Olympic lifting platform) was marked with tape to ensure that the same location was used for each testing session. The force plate was zeroed before the jump testing battery and again after moving the plate into the IMTP testing rack. For each trial, subjects were instructed to be as still as possible before movement because any talking, looking around, or deep inhales may disrupt estimations of bodyweight and force data integration. Additionally, all jumps were completed without an arm swing by having subjects hold a polyvinyl chloride pipe placed across their shoulders. Each trial was performed with maximal effort and verbal encouragement was provided. Finally, subjects were instructed to land back on the force plates and stand as quickly as possible, then remain as still as possible in the erect standing position for 2–3 seconds for all jumping trials.

Although procedures for performing assessments are similar when testing with each force plate software, there are slight variations in the procedures and analyses across the 2 force plate software manufacturers (e.g., when and how system weight is calculated, what nullifies a trial). For ForceDecks analysis, the individual remained as still as possible on the force plate in a standing position until system mass was accepted under the following criteria: at least 1 motionless second with maximal body mass deviation of 0.1 kg and maximal *SD* of 2 (this can be adjusted in the ForceDecks software to be more or less stringent). The same ForceDecks system weight was used for all jump tests and was reassessed for the IMTP trials to include the slight

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pretension forces from pulling slack out of the bar to allow accurate timing of movement initiation. For all testing, the subjects were asked to remain in the starting position for the given test as still as possible for 2–3 seconds before the "go" command was given. For postprocessing by Hawkin Dynamics and MATLAB, system weight was calculated from the first 1 second of quiet phase data collection before the initiation of movement (also including pretension in system mass for IMTP trials). The Hawkin Dynamics software documents system mass for the drop jump as the average system mass from all trials of the squat jump and countermovement jump performed before the drop jump, whereas MATLAB analysis in the current study calculated system mass in the drop jump from 1 second during the stable quiet phase at the end of the drop jump trial.

Squat Jump. Subjects assumed a squatted position at a self-selected depth "similar to the depth reached during typical vertical jumping" and remained as still as possible. This resulted in a knee flexion angle of approximately 60–90° and is a common strategy for practitioners when not comparing data to research norms. Subjects were then instructed to jump straight up, with no countermovement dip, as high and as explosively as possible, then land back on the force plate, come to a standing tall and stable position as quickly as possible and remain there until instructed otherwise. If there was too much countermovement, the trial was discarded and subjects were instructed to perform an additional squat jump. During ForceDecks testing, the researcher visually assessed the force-time curve and subject to identify any excessive countermovement. During Hawkin Dynamics testing, a threshold was set by the manufacturer's software, where a countermovement of >5% below system weight resulted in a null test.

Countermovement Jump. Subjects began each countermovement jump in the standing tall position, knees slightly bent, and as still as possible. The subjects were instructed to drop into a self-selected countermovement depth, jump as high and as explosively as possible, and then land back onto the force plates. After landing, subjects were instructed to return to the standing tall position and remain as still as possible for 2–3 seconds. If the subject ascended before initiating downward movement (i.e., countercountermovement) or did not land back on the force plate, the trial was nullified and repeated.

Drop Jump. Subjects began each drop jump by standing on top of the plyometric box placed approximately 15 cm from the force plates. The top of the box was approximately 48 cm from the top of the force plates. The subject was instructed to step off the box using their right leg without jumping or stepping down from the box and to land on the force plate. They were instructed to perform a maximal effort countermovement vertical jump immediately upon ground contact and stabilize the subsequent landing quickly, then stay as still as possible for 2–3 seconds. The trial was discarded and repeated if the subject lost balance during the trial or did not properly step off the box.

Isometric Mid-thigh Pull. The IMTP was conducted in a custom-designed power rack (Sorinex, Inc., Irmo, SC) specifically designed to fix the bar at any desired height above the force plates. The bar was set at approximately half the thigh length (50% of the distance between the greater trochanter and lateral epicondyle of the knee) to place the subjects in a fixed, standard, power-pulling position, as identified in previously published work (6,34). After positioning, subjects' hands were strapped to the bar using wrist straps and standard athletic tape to remove any effect of grip strength on IMTP performances. The bar was completely immoveable to ensure accurate readings by removing the "slack" in the bar that would result in signal noise. Subjects were instructed to pull upward on the bar "as quickly and as hard as possible" and maintain maximal effort for at least 3 seconds.

Kinetic Data Analysis. All vGRFs were collected using a single Bertec force plate (Model FP4060-05-PT; Bertec Corp.) at a sampling rate of 1,000 Hz. Custom analyses were conducted using MATLAB version 7.12 software (R2011a; MathWorks, Natick, MA). Example code is provided as Supplemental Digital Contents 1–4 (http://links.lww.com/JSCR/A328) for squat jump, countermovement jump, drop jump, and IMTP, respectively. The vGRF data from the Bertec force plate was also analyzed by ForceDecks (Jump Application v2.0.7782; Vald Performance, Brisbane, QLD, Australia) and Hawkin Dynamics (Hawkin Dynamics, Westbrook, ME). For the MATLAB analysis, the vGRF data were not filtered because previous evidence has suggested that this step to not be necessary (16). ForceDecks and Hawkin Dynamics also did not use a filter in their analyses of this Bertec vGRF data (however, when Hawkin Dynamics plates are being used, they have a current default low-pass filter at 50 Hz unless required changes are made). All key landmarks were visually inspected after analyses. If the initial start of movement was vastly incorrect (too early or too late; see Figure 1 for examples), the trial was removed to make more appropriate comparisons. All phases for each movement across all software analyses are outlined in Table 1.

The braking phase of Hawkin Dynamics analysis corresponds to the deceleration phase and eccentric phase of the ForceDecks analysis for the countermovement and drop jump, respectively. The propulsive phase of the Hawkin Dynamics corresponds to the concentric phase of ForceDecks analysis for all jumping testing. The phases in the MATLAB script were made to coincide with each provided phase from Hawkin Dynamics and ForceDecks using custom thresholds defined in Table 1. The integration process for squat and countermovement jumps for Hawkin Dynamics and ForceDecks began at the initiation of movement (Table 1) as 0 $m\cdot s^{-1}$. However, for the MATLAB analysis, integration began at the start of the trial including the 1-second quiet standing phase to introduce some variation because this may be adjusted in some software. For drop jump analysis of all procedures, initial velocity began by using standard physics calculations with the acceleration of gravity and the set drop height, which equaled approximately 3.07 $m\cdot s^{-1}$. No integration was used for the IMTP because only raw vGRF data were assessed. Metrics in correspondence across analyses are listed in Table 2.

Statistical Analyses

An a priori power analysis (MedCalc 19.2.1) determined the minimum sample size required to find significance was 70 trials. The analysis was executed based on agreement methods (i.e., Bland-Altman plots), derived from minimum differences noted in pilot testing, and included the following criteria: desired level of power = 0.80, α-level = 0.05, jumping values for expected mean differences = 1.0 cm, expected *SD*s of differences = 0.7 cm, and maximal allowed difference = 2.54 cm; IMTP values for expected mean difference = 10 N, standard error = 15 N, and maximal difference = 50 N. Since linear regressions and correlations can demonstrate strong associations and relations

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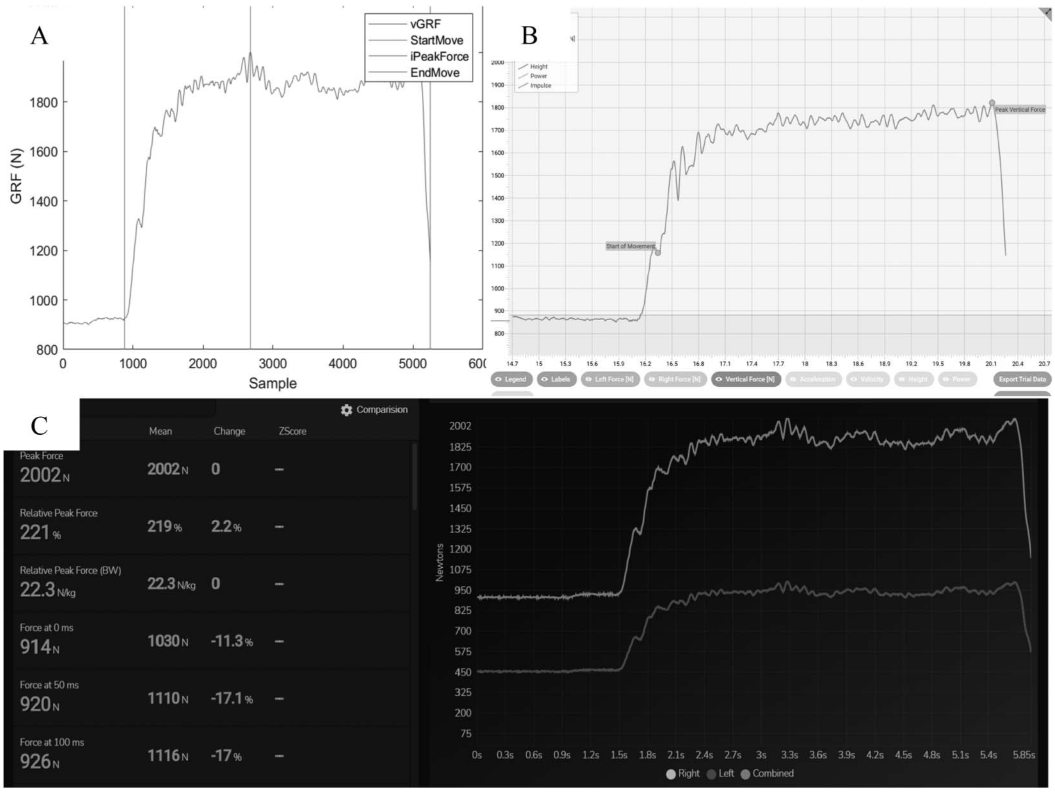

	Mean	Change	ZScore
Peak Force 2002 N	2002 N	0	–
Relative Peak Force 221 %	219 %	2.2 %	–
Relative Peak Force (BW) 22.3 N/kg	22.3 N/kg	0	–
Force at 0 ms 914 N	1030 N	-11.3 %	–
Force at 50 ms 920 N	1110 N	-17.1 %	–
Force at 100 ms 926 N	1116 N	-17 %	–

Figure 1. Demonstration of potential errors, which requires subsequent verification of landmark identifications before using analyses. The MATLAB script results (A) correctly identified the onset of movement, demonstrating an example of how these errors may differ across analyses from trial to trial. ForceDecks analysis (B) demonstrated a clearly late identification of movement onset, which is shown in the software. Although jump trials show braking and propulsive phases, the Hawkin Dynamics software (C) does not show landmark identification for the isometric mid-thigh pull. Instead, the force at 0 through 100 milliseconds is very similar, likely suggesting the initiation of movement was premature. These errors may be the result of slightly inconsistent pretensions, where a small raise in forces before starting the movement resulted in error. vGRF = vertical ground reaction force.

between arrays of data that are in poor agreement, they were not used in the current analysis. For example, high correlations may exist when the values are consistently low or high across a data set in comparison to the criterion method, but the actual agreement is then considered poor. Although a paired *t* test can be used in conjunction with these methods, these analyses only address the significant difference of the mean of each data set and not the systematic or proportional bias of all individual trials. Instead, ordinary least products (Model II linear regression; "sma" function within the "smatr" package) (44) regressions were used to determine systematic and proportional bias while allowing x-values to vary freely (23,24,29). Systematic bias was present when the 95% confidence interval of the intercept did not include "0," whereas proportional bias was present when the 95% confidence interval of the slope did not include "1.0." If either analysis determined systematic or proportional biases, it was determined that the force plates in comparison should not be used interchangeably (while also considering the practical size of the systematic difference). Additionally, Bland-Altman plots were created to display data for comparisons of main outcome metrics using the 95% limits of agreement technique (mean bias ± [1.96 × *SD* of differences]). Finally, the percent difference between devices was calculated as the differences between each trial divided by the original comparison trial multiplied by 100. A difference of >5% was considered as a practically meaningful difference. All statistical procedures were conducted using R, version 4.0.1 (R Core Team, Vienna, Austria; https://www.R-project.org) with alpha level set to <0.05. For an overall description of means and *SD*s of MATLAB analysis outputs for each metric for each assessment, please see Supplemental Digital Content 5 (http://links.lww.com/JSCR/A329).

Results

Squat Jump Comparisons

For Hawkin Dynamics to MATLAB comparisons, there was no systematic bias for any variable, but proportional bias existed for Propulsive Average Force, and RFD (Table 3). ForceDecks to MATLAB comparisons revealed systematic bias for jump height by flight time, propulsive RFD, flight time, and system weight and proportional bias for propulsive RFD, flight time, and system weight (Table 4). Finally, comparisons between Hawkin Dynamics and ForceDecks revealed systematic bias for flight time and system weight, as well as proportional bias for propulsive duration and system weight (Table 5). ForceDecks comparisons to Hawkin Dynamics and MATLAB for the propulsive impulse resulted in weaker associations ($R^2 = 51.44–52.15$) and higher percent overestimations in impulse values (Tables 4 and 5). Select

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Table 1

Comparisons of analyses for determining phases of each movement.*

Phase	Hawkin Dynamics	ForceDecks	MATLAB
Squat jump			
Propulsive/concentric†	From when vGRF rise 5 *SD* above BW then backtracked to within 0–2 N of BW until vGRF fall below 25 N for 30 milliseconds (takeoff)	From point where a 20 N threshold is exceeded until force falls below 30 N (takeoff)	From when vGRF rise 5 *SD* above BW then backtracked to within 1 *SD* of BW until vGRF falls below 30 N (takeoff)
Countermovement jump			
Unweighing	Negative velocity from when vGRF falls 5 *SD* below BW backtracked to within 0–2 N of BW until peak eccentric velocity	NA	Negative velocity from when vGRF falls 5 *SD* below BW backtracked to within 1 *SD* of BW until peak eccentric velocity
Eccentric	NA	Negative velocity starting from point where a 20 N threshold is exceeded until velocity = 0 m·s^{-1}	Negative velocity starting when vGRF falls 5 *SD* below bodyweight, backtrack to 1 *SD* of BW
Braking	Negative velocity ascending from peak eccentric velocity until 0 m·s^{-1}	Eccentric subphase: point of minimum force until velocity = 0 m·s^{-1}	Eccentric subphase: point of minimum force until end of eccentric phase
Deceleration	NA	Eccentric subphase: peak negative velocity to 0 m·s^{-1}	Eccentric subphase: peak negative velocity to 0 m·s^{-1}
Propulsive/concentric	Positive velocity from 0 m·s^{-1} until takeoff	Positive velocity from 0 m·s^{-1} until takeoff	Positive velocity from 0 m·s^{-1} until takeoff
Drop jump			
Braking/eccentric/drop landing	From 30 N (for 30 milliseconds) (contact) until velocity = 0 m·s^{-1}	From contact when a 20 N threshold is exceeded until velocity = 0 m·s^{-1}	From contact when a 30 N threshold is exceeded until velocity = 0 m·s^{-1}
Propulsive/concentric	Positive velocity from 0 m·s^{-1} until takeoff	Positive velocity from 0 m·s^{-1} until takeoff	Positive velocity from 0 m·s^{-1} until takeoff
Flight and landing phase for all jumps			
Flight	From when vGRF falls below 25 N (for 30 milliseconds) to landing point when vGRF returns above 25 N (for 30 milliseconds)	From when vGRF falls below 30 N until vGRF return to above 30 N (landing point)	From when vGRF falls below 30 N until vGRF return to above 30 N (landing point)
Landing	From landing point until forces settle to back to BW	From landing point until forces settle to back to BW	From landing point until forces settle to back to BW
Isometric mid-thigh pull			
Start of movement	5 *SD* above bodyweight then backtracked to within 0–2 N of BW	Point where exercise commences.	5 *SD* above bodyweight then backtracked to within 1 *SD* of BW
Peak force	Greatest force during trial	Greatest force during trial	Greatest force during trial

*vGRF = vertical ground reaction force; *SD* = *SD* of bodyweight phase (1 second of data before movement); BW = mean bodyweight value during the 1-second quit phase before movement (or estimated bodyweight before movement for ForceDecks).

†ForceDecks concentric phase and deceleration phase corresponds to Hawkin Dynamics propulsive phase and braking phase for jump testing.

comparisons among a few standard squat jump performance metrics are presented in Figure 2.

Countermovement Jump Comparisons

For comparisons between MATLAB and Hawkin Dynamics, there was systematic bias for jump height, average braking and propulsive force, velocity, and power, braking impulse, duration, and RFD, peak braking force and power, peak propulsive velocity and power, and propulsive duration and impulse, but the magnitude of error was considered small, and all metrics demonstrated very strong associations (Table 6). The small errors demonstrated proportional bias for average braking force and power, braking duration and RFD, peak braking force, average propulsive power and force, peak propulsive velocity, propulsive impulse, flight time, and takeoff velocity (Table 6). For comparisons between MATLAB and ForceDecks, systematic and/or proportional bias was noted for all metrics except takeoff velocity, countermovement depth, peak eccentric velocity, braking and deceleration durations, average propulsive force, peak propulsive force, and velocity, propulsive duration, and peak landing force (Table 7). However, practically notable overestimation errors occurred for average and peak deceleration power and underestimation errors occurred for propulsive RFD (Table 7). Finally, comparisons between Hawkin Dynamics and ForceDecks revealed systematic bias and/or proportional bias for all metrics except flight time, countermovement depth, peak braking power and force, braking duration, peak propulsive, and landing forces (Table 8). However, practically notable overestimation errors occurred for average and peak deceleration power (Table 8). Furthermore, weak associations were also noted for RFD metrics (Table 8). For sake of brevity, select comparisons among a few standard countermovement jump performance metrics are presented in Figure 3.

Drop Jump Comparisons

For comparisons between MATLAB and Hawkin Dynamics, there was no systematic or proportional bias for average braking and propulsive force, takeoff velocity, flight time, reactive strength index (RSI), braking duration, peak braking force, peak propulsive velocity, propulsive duration and impulse, and peak landing force (Table 9). Although jump height did not demonstrate systematic error, the underestimation was more likely at higher jump heights according to the proportional bias and Bland-Altman plots (Figure 4). Furthermore, the percent difference between all Hawkin Dynamics trials compared with MATLAB analysis were trivial (Table 9), and all metrics demonstrated very strong associations (Table 9). For comparisons between MATLAB and ForceDecks, there was no systematic or proportional bias for jump height by impulse momentum and flight time calculations, takeoff velocity, countermovement depth, peak

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Table 2

Metrics compared across Hawkin Dynamics and Vald ForceDecks for each assessment.*

Test type	Hawkin Dynamics (measurement units)	Vald ForceDecks (measurement units)
CMJ	Avg braking force (N)	Eccentric mean deceleration force (N)
DJ	Avg braking force (N)	Eccentric mean force (N)
CMJ	Avg braking power (W)	Eccentric mean power (W)
CMJ	Peak braking force (N)	Eccentric peak force (N)
DJ	Peak braking force (N)	Peak drop landing force (N)
CMJ	Peak braking power (W)	Eccentric peak power (W)
CMJ	Braking net impulse (N·s)	Eccentric deceleration impulse (N·s)
DJ	Braking net impulse (N·s)	Eccentric impulse (N·s)
CMJ	Braking phase (s)	Eccentric deceleration phase duration (s)
DJ	Braking phase (s)	Drop landing (s)
CMJ	Braking RFD (N·s^{-1})	Eccentric deceleration RFD (N·s^{-1})
CMJ, DJ, SJ	Avg propulsive power (W)	Concentric mean power (W)
CMJ, DJ, SJ	Avg propulsive force (N)	Concentric mean force (N)
CMJ, DJ, SJ	Peak propulsive power (W)	Peak power (W)
CMJ, SJ	Peak propulsive force (N)	Concentric peak force (N)
DJ	Peak propulsive force (N)	Peak drive off force (N)
CMJ, DJ, SJ	Peak velocity (m·s^{-1})	Concentric peak velocity (m·s^{-1})
CMJ	Propulsive phase (s)	Concentric duration (milliseconds)
SJ	Propulsive phase (s)	Contraction time (milliseconds)
DJ	Contact time (s)	Contact time (s)
CMJ, DJ, SJ	Propulsive net impulse (N·s)	Concentric impulse (N·s)
SJ	Propulsive RFD (N·s^{-1})	Concentric RFD (N·s^{-1})
CMJ, DJ, SJ	Peak landing force (N)	Peak landing force (N)
CMJ, DJ, SJ	System weight (N)	Body mass (kg) × 9.81 m·s^{-1} (gravity)
CMJ	Countermovement depth (m)	Countermovement depth (cm)
CMJ, DJ, SJ	Flight time (s)	Flight time (milliseconds)
CMJ	mRSI (m·s^{-1})	mRSI (m·s^{-1})
DJ	RSI (ratio of flight time/contact time)	RSI (ratio of flight time/contact time)
DJ	mRSI (m·s^{-1})	RSI (jump height [flight time]/contact time) (m·s^{-1})
CMJ, SJ	Takeoff velocity (m·s^{-1})	Vertical velocity at takeoff (m·s^{-1})
SJ, CMJ, DJ	Jump height (m)	Jump height (imp-mom) (cm)
IMTP	Peak force (N)	Peak vertical force (N)
IMTP	Time to peak force (s)	Start time to peak force (s)
IMTP	Force at 0 millisecond (N)	Baseline force (N)
IMTP	Force at 50 milliseconds (N)	Force at 50 milliseconds (N)
IMTP	Force at 100 milliseconds (N)	Force at 100 milliseconds (N)
IMTP	Force at 150 milliseconds (N)	Force at 150 milliseconds (N)
IMTP	Force at 200 milliseconds (N)	Force at 200 milliseconds (N)
IMTP	RFD 0–50 milliseconds (N·s^{-1})	RFD: 50 milliseconds (N·s^{-1})
IMTP	RFD 0–100 milliseconds (N·s^{-1})	RFD: 100 milliseconds (N·s^{-1})
IMTP	RFD 0–150 milliseconds (N·s^{-1})	RFD: 150 milliseconds (N·s^{-1})
IMTP	RFD 0–250 milliseconds (N·s^{-1})	RFD: 250 milliseconds (N·s^{-1})

*CMJ = countermovement jump; Avg = average; DJ = drop jump; SJ = squat jump; IMTP = isometric mid-thigh pull; RSI = reactive strength index; mRSI = modified RSI; RFD = rate of force development.

eccentric, propulsive, and landing force (Table 10). Despite no clear systematic bias, RSI, modified RSI, average propulsive force, and peak propulsive velocity demonstrated proportional bias (Table 10). Furthermore, drop landing (eccentric) RFD associations were weaker in comparisons with the other metrics. Finally, comparisons between Hawkin Dynamics and ForceDecks revealed no systematic or proportional bias for takeoff velocity, peak eccentric force, peak propulsive force, peak propulsive velocity, peak landing force (Table 11). Although there was no systematic bias, coinciding with strong associations and low error (Table 11) for jump height, RSI, and average propulsive force, there was propulsive bias. Braking duration compared with drop landing duration was not significantly associated and resulted in large systematic and proportional bias. Large errors also existed for average and peak propulsive power, as well as modified RSI (Table 11). Select comparisons among a few standard drop jump performance metrics are presented in Figure 4.

Isometric Mid-thigh Pull Comparisons

For comparisons between MATLAB and Hawkin Dynamics, systematic bias existed for peak force, but the magnitude of underestimation errors were generally within 1 N (Table 12, Figure 5). All other metrics demonstrated no systematic or proportional bias, except forces at 0 millisecond (Table 12). For comparisons between MATLAB and ForceDecks, there was only systematic bias for force at 0 millisecond (Table 13), but proportional bias was noted for force at 0, 50, and 150 milliseconds and RFD from 0 to 50, 100, and 150 milliseconds (Table 13). Furthermore, percent differences were greater than 10% for all RFD time bands, as well as force at 50 and 100 milliseconds (Table 13). ForceDecks comparisons to Hawkin Dynamics revealed small systematic bias for peak force and time to peak force (Table 14). However, proportional bias was noted for all metrics except time to peak force and RFD from 0 to 250

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Table 3

MATLAB and Hawkin Dynamics (n = 127) comparisons for squat jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
System weight (N)	99.88	−2.32 (−7.18 to 2.55)	1.001 (0.995 to 1.008)	−0.17 (−0.28 to −0.06)
Jump height (cm)	96.88	−0.33 (−0.51 to 1.17)	0.981 (0.951 to 1.012)	−0.46 (−1.45 to 0.53)
Flight time (s)	99.59	0.001 (−0.004 to 0.006)	0.995 (0.984 to 1.007)	0.00 (−0.01 to 0.01)
Takeoff velocity (m·s^{-1})	97.23	0.016 (−0.050 to 0.081)	0.990 (0.961 to 1.019)	−0.33 (−0.5 to −0.16)
Avg propulsive power (W)	96.86	16.54 (−25.22 to 58.30)	0.990 (0.960 to 1.022)	−0.27 (−0.77 to 0.22)
Avg propulsive force (N)	99.66	−7.65 (−20.89 to 5.60)	1.014 (1.004 to 1.024)†	0.53 (−0.39 to 1.46)
Avg propulsive velocity (m·s^{-1})	87.64	−0.030 (−0.128 to 0.086)	0.968 (0.910 to 1.030)	0.77 (0.55 to 0.98)
Peak propulsive power (W)	99.19	16.31 (−41.66 to 74.28)	0.989 (0.974 to 1.005)	0.23 (−0.72 to 1.18)
Peak propulsive force (N)	99.99	0.325 (−0.128 to 0.777)	0.999 (0.999 to 1.000)	−0.55 (−1.04 to −0.05)
Peak propulsive velocity (m·s^{-1})	96.72	0.015 (−0.060 to 0.090)	0.989 (0.958 to 1.021)	0.00 (−0.01 to 0.01)
Propulsive duration (s)	96.57	0.004 (−0.008 to 0.017)	0.970 (0.939 to 1.002)	−0.42 (−0.88 to 0.05)
Propulsive impulse (N·s)	99.88	0.374 (−0.732 to 1.481)	0.997 (0.991 to 1.003)	−0.06 (−0.24 to −0.12)
Propulsive RFD (N·s^{-1})	77.96	1,028 (−928 to 1,127)	0.278 (0.256 to 0.301)†	−1.10 (−1.45 to −0.74)
Peak landing force (N)	99.99	1.74 (−3.28 to 6.75)	0.999 (0.999 to 1.001)	0.21 (−0.32 to 0.73)

*Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

milliseconds. Moreover, large percent error was noted for force at 50 and 100 milliseconds, as well as RFD from 0 to 50, 100, and 150 milliseconds (Table 14). Select comparisons among a few standard IMTP performance metrics are presented in Figure 5.

Discussion

The purpose of this study was to determine the agreement among commercially available automated analyses and custom MATLAB analyses of force-time data from squat jump, countermovement jump, drop jump, and IMTP performances. Human performance practitioners and scientists are tasked with either developing custom analysis in software programs, such as Microsoft Excel (5) or MATLAB (15), or relying on commercially available software (12,17). One strength of custom analyses is the ability to make corrections based on visual inspection of the force-time data (i.e., the force-time curve) for accuracy during analysis. Since invalid trials should be removed from typical analyses, all trials were visually inspected (Figure 1) to verify the accuracy of landmark identifications (i.e., onset of movement detection) and removed if obvious errors occurred. As a direct example of this, the number of removed trials in this study are as follows: Hawkin Dynamics: squat jump = 12 trials (9.3%), countermovement jump = 13 (10%), drop jump = 3 (2%), IMTP = 13 trials (10%): ForceDecks: squat jump = 10 (7.5%), countermovement jump = 0 (0%), drop jump = 18 (14%), IMTP = 10 (7.2%).

Slight differences in landmark identifications may also occur because of variations in filtering techniques, which may cause deviations in raw force-time curves (10,41). However, differences as a result of filtering techniques is unlikely because the MATLAB analyses did not filter the force time data, as this may not be necessary (16), and neither did Hawkin Dynamics and ForceDecks analyses. The integration process (e.g., velocity from acceleration, displacement from velocity) for Hawkin Dynamics and ForceDecks began at the initiation of movement at 0 or approximately 3.07 m·s^{-1} when landing from the box during drop jumps. The MATLAB analyses' integration for countermovement and squat jumps began at the start of the trial, including the 1-second quiet standing phase, which may result in slight integration drift in comparison to starting with 0 m·s^{-1} at the start of movement. Thus, starting velocity for the commercial analyses of squat and countermovement jump was 0 m·s^{-1}, although MATLAB analyses resulted in a slight deviation from 0 m·s^{-1}. Although any differences in the initial starting velocity will alter

Table 4

MATLAB ~ ForceDecks (n = 134) comparisons for squat jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
System weight (N)	99.95	4.955 (1.846 to 8.065)†	0.993 (0.989 to 0.997)†	−0.07 (−0.14 to 0.01)
Jump height (cm)	98.17	0.254 (−0.366 to 0.874)	0.997 (0.974 to 1.020)	0.91 (0.2 to 1.61)
Jump height by flight (cm)	99.80	0.375 (0.166 to 0.583)†	0.995 (0.987 to 1.002)	1.08 (0.86 to 1.29)
Flight time (s)	99.86	0.007 (0.004 to 0.010)†	0.990 (0.983 to 0.996)†	0.52 (0.41 to 0.63)
Takeoff velocity (m·s^{-1})	98.39	0.029 (−0.019 to 0.077)	0.991 (0.969 to 1.013)	0.44 (0.09 to 0.8)
Avg propulsive power (W)	93.10	−5.38 (−66.55 to 55.79)	0.980 (0.937 to 1.025)	−2.07 (−3.98 to −0.15)
Avg propulsive force (N)	96.49	9.09 (−32.24 to 50.41)	0.989 (0.958 to 1.022)	−0.28 (−1.05 to 0.5)
Peak propulsive power (W)	99.61	−26.08 (−65.69 to 13.53)	1.008 (0.997 to 1.019)	0.03 (−0.3 to 0.37)
Peak propulsive force (N)	99.99	−0.031 (−0.235 to 0.172)	1.000 (0.999 to 1.000)	0.00 (0.00 to 0.00)
Peak propulsive velocity (m·s^{-1})	98.21	−0.005 (−0.059 to 0.050)	1.003 (0.980 to 1.026)	0.07 (−0.25 to 0.38)
Propulsive duration (s)	79.79	−0.014 (−0.046 to 0.017)	1.065 (0.986 to 1.150)	2.98 (1.44 to 4.51)
Propulsive impulse (N·s)	99.78	1.42 (−0.062 to 2.901)	1.000 (0.992 to 1.008)	0.86 (0.61 to 1.11)
Propulsive RFD (N·s^{-1})	74.15	957 (846 to 1,068)†	0.292 (0.267 to 0.318)†	−2.41 (−5.3 to 0.48)
Peak landing force (N)	99.99	−0.015 (−0.128 to 0.099)	1.000 (1.000 to 1.000)	0.00 (0.00 to 0.00)

*Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including "0" and Slope as not including "1" OR practically meaningful percent difference of >5%.

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Table 5

Hawkin Dynamics and ForceDecks (n = 121) comparisons for squat jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
System weight (N)	99.82	7.27 (1.26 to 13.28)†	0.991 (0.983 to 0.999)†	0.08 (−0.06 to 0.22)
Jump height (cm)	98.20	0.256 (−0.392 to 0.903)	0.998 (0.974 to 1.022)	1.06 (0.28 to 1.83)
Flight time (s)	99.75	0.006 (0.002 to 0.010)†	1.005 (0.996 to 1.014)	0.81 (0.65 to 0.97)
Takeoff velocity ($m \cdot s^{-1}$)	98.35	0.031 (−0.021 to 0.082)	0.991 (0.968 to 1.014)	0.52 (0.12 to 0.91)
Avg propulsive power (W)	90.59	−4.33 (−78.37 to 69.71)	0.967 (0.915 to 1.022)	−3.16 (−5.42 to −0.90)
Avg propulsive force (N)	96.52	15.34 (−27.31 to 57.99)	0.975 (0.943 to 1.061)	−1.17 (−1.95 to −0.40)
Peak propulsive power (W)	99.61	−18.66 (−62.54 to 25.21)	1.009 (0.997 to 1.022)	0.39 (0.03 to 0.76)
Peak propulsive force (N)	99.99	−0.347 (−0.913 to 0.219)	1.000 (0.999 to 1.005)	0.00 (−0.01 to 0.01)
Peak propulsive velocity ($m \cdot s^{-1}$)	98.10	0.010 (−0.0492 to 0.069)	0.999 (0.974 to 1.024)	0.32 (−0.03 to 0.68)
Propulsive duration (s)	79.76	−0.021 (−0.059 to 0.017)	1.107 (1.011 to 1.213)†	5.31 (3.61 to 7.02)†
Propulsive impulse (N·s)	99.74	0.474 (−1.234 to 2.182)	1.006 (0.997 to 1.015)	0.89 (0.62 to 1.17)
Propulsive RFD ($N \cdot s^{-1}$)	84.63	−176.5 (−490.1 to 137.2)	1.015 (0.945 to 1.090)	−2.71 (−5.66 to 0.24)
Peak landing force (N)	99.99	−1.85 (−7.09 to 3.39)	1.001 (0.999 to 1.001)	−0.04 (−0.12 to 0.04)

*Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

the identification of phases based on velocity thresholds (i.e., eccentric subphases and propulsive/concentric phase of countermovement jump), the slight variation in integration timing in the current MATLAB analysis seemingly resulted in minimal differences compared with Hawkin Dynamics and ForceDecks analyses. Otherwise, integration errors affect velocity-based (i.e., jump height by impulse momentum theorem) or displacement-based (i.e., countermovement depth) metrics, although errors in these metrics across devices were mostly minimal according to current results (Tables 3–8 and Figures 2 and 3).

Overall, many precautions are necessary because any deviations in raw force-time curves cause integration errors, which supports rationale for only comparing across the same analysis (i.e., software) unless absolutely necessary (43). Finally, accuracy of identifying the onset of movement can be improved using a 5-system weight *SD* threshold (9,39) to account for variability during the weighting

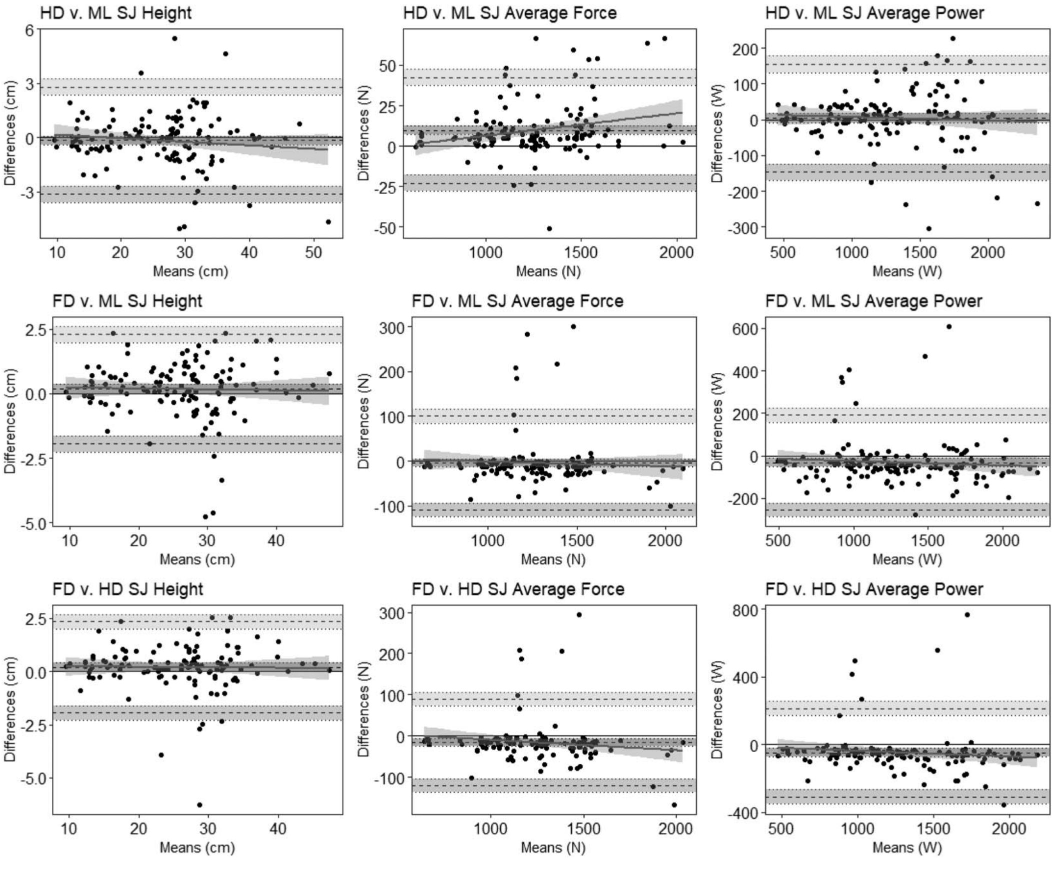

Figure 2. Select comparisons among ForceDecks (FD), Hawkin Dynamics (HD), and custom MATLAB (ML) scripts for analyzing squat jump (SJ) metrics. Each black dot represents a trial where the blue-(or dark gray), green-(or light gray), and red-(or mid gray, lower bound) shaded areas are the respective value and 95% confidence intervals surrounding the mean, upper, and lower 95% confidence interval, respectively. The solid gray line with shaded gray area represents the slope and the respective bounds.

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Table 6

MATLAB ~ Hawkin Dynamics (*n* = 132) comparisons for countermovement jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
System weight (N)	99.99	−0.049 (−0.762 to 0.664)	0.999 (0.999 to 1.001)	−0.02 (−0.03 to 0)
Jump height (cm)	99.75	0.5233 (0.241 to 0.805)†	0.996 (0.988 to 1.005)	1.59 (1.24 to 1.94)
Flight time (s)	99.25	0.007 (−0.001 to 0.015)	0.984 (0.969 to 0.999)†	−0.20 (−0.42 to 0.02)
Takeoff velocity (m·s^{-1})	99.74	0.057 (0.036 to 0.079)†	0.984 (0.975 to 0.992)†	0.80 (0.63 to 0.97)
Countermovement depth (cm)	95.89	0.263 (−0.899 to 1.425)	0.986 (0.952 to 1.021)	−2.19 (−2.78 to −1.6)
RSI (AU)	98.14	0.003 (−0.012 to 0.018)	0.996 (0.972 to 1.019)	1.93 (1.4 to 2.46)
Modified RSI (m·s^{-1})	99.10	0.002 (−0.005 to 0.008)	1.012 (0.996 to 1.029)	0.12 (−0.37 to 0.61)
Unweighting duration (s)	92.88	0.011 (−0.005 to 0.026)	0.961 (0.918 to 1.007)	−0.59 (−1.38 to 0.2)
Avg braking power (W)	99.86	9.293 (2.555 to 16.031)†	0.990 (0.983 to 0.996)†	−2.15 (−2.43 to −1.86)
Avg braking force (N)	99.99	−6.078 (−8.574 to −3.583)†	1.005 (1.004 to 1.007)†	0.05 (0.00 to 0.10)
Avg braking velocity (m·s^{-1})	99.44	0.015 (0.005 to 0.026)†	1.000 (0.987 to 1.013)	−1.97 (−2.22 to −1.71)
Peak braking power (W)	99.87	15.888 (7.062 to 24.714)†	1.000 (0.994 to 1.006)	−1.38 (−1.68 to −1.09)
Peak braking force (N)	99.99	−5.400 (−8.737 to −2.063)†	1.004 (1.002 to 1.006)†	0.05 (0.01 to 0.10)
Braking duration (s)	99.74	0.002 (0.001 to 0.004)†	0.983 (0.975 to 0.992)†	−0.4 (−0.57 to −0.23)
Braking impulse (N·s)	99.77	−1.885 (−2.743 to −1.027)†	1.023 (1.015 to 1.032)†	0.20 (−0.12 to 0.51)
Braking RFD (N·s^{-1})	99.99	27.03 (14.96 to 39.10)†	0.997 (0.995 to 0.999)†	0.38 (0.24 to 0.52)
Avg propulsive power (W)	99.95	17.76 (9.53 to 25.98)†	0.996 (0.992 to 0.999)†	0.63 (0.46 to 0.80)
Avg propulsive force (N)	99.99	5.91 (3.48 to 8.34)†	0.993 (0.992 to 0.995)†	−0.24 (−0.29 to −0.19)
Avg propulsive velocity (m·s^{-1})	99.76	0.017 (0.005 to 0.029)†	0.998 (0.999 to 1.006)	1.01 (0.87 to 1.15)
Peak propulsive power (W)	99.95	30.59 (15.41 to 45.78)†	0.998 (0.994 to 1.001)	0.69 (0.53 to 0.85)
Peak propulsive force (N)	99.99	0.194 (−0.283 to 0.671)	1.000 (0.999 to 1.000)	0.01 (0 to 0.02)
Peak propulsive velocity (m·s^{-1})	99.74	0.045 (0.023 to 0.067)†	0.988 (0.980 to 0.997)†	0.64 (0.5 to 0.79)
Propulsive duration (s)	99.80	−0.004 (−0.007 to −0.002)†	1.018 (1.010 to 1.026)	0.22 (0.11 to 0.34)
Propulsive impulse (N·s)	99.93	2.531 (1.575 to 3.487)†	0.987 (0.982 to 0.992)†	0.11 (−0.05 to 0.28)
Peak landing force (N)	99.78	6.97 (−27.58 to 41.51)	1.001 (0.993 to 1.009)	0.26 (−0.13 to 0.65)

*RSI = reactive strength index; Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including “0” and slope as not including “1” OR practically meaningful percent difference of >5%.

Table 7

MATLAB ~ ForceDecks (*n* = 144) comparisons for countermovement jump metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
System weight (N)	99.95	9.296 (6.267 to 12.324)†	0.987 (0.983 to 0.991)†	−0.06 (−0.14 to 0.02)
Jump height (cm)	98.20	−0.059 (−0.791 to 0.673)	1.026 (1.003 to 1.049)†	2.57 (1.9 to 3.24)
Jump height flight time (cm)	99.52	0.722 (0.034 to 1.103)†	0.982 (0.971 to 0.994)†	0.72 (0.44 to 1)
Flight time (s)	99.66	0.011 (0.006 to 0.016)†	0.981 (0.972 to 0.991)†	0.33 (0.19 to 0.47)
Takeoff velocity (m·s^{-1})	98.33	0.015 (−0.037 to 0.068)	1.001 (0.985 to 1.028)	1.23 (0.85 to 1.6)
Countermovement depth (cm)	95.89	0.2356 (−1.008 1.479)	0.986 (0.949 to 1.024)	−2.09 (−2.79 to −1.38)
Modified RSI ImpMom (m·s^{-1})	96.58	−0.009 (−0.022 to 0.004)	0.961 (0.932 to 0.991)†	−2.9 (−3.79 to −2.02)
Avg eccentric power (W)	96.59	43.23 (26.81 to 59.65)†	−1.014 (−1.046 to −0.984)†	−192 (−193 to −191)†
Avg eccentric force (N)	99.90	5.241 (1.297 to 9.186)†	0.990 (0.985 to 0.995)†	−0.28 (−0.38 to −0.19)
Avg braking force (N)	99.77	5.625 (−1.909 to 13.159)	0.992 (0.984 to 0.999)†	−0.16 (−0.33 to 0.01)
Avg deceleration force (N)	99.97	5.720 (1.725 to 9.716)†	0.994 (0.991 to 0.997)†	−0.17 (−0.25 to −0.09)
Peak eccentric power (W)	99.74	2.130 (−9.871 to 14.131)	−0.988 (−0.996 to −0.979)†	−198 (−199 to −198)†
Peak eccentric force (N)	99.98	3.014 (−0.861 to 6.888)	0.997 (0.995 to 0.999)†	−0.06 (−0.12 to 0)
Peak eccentric velocity (m·s^{-1})	99.21	0.015 (−0.003 to 0.033)	1.001 (0.987 to 1.016)	−1.14 (−1.48 to −0.80)
Braking duration (s)	99.72	0.001 (−0.003 to 0.003)	0.995 (0.986 to 1.003)	−0.40 (−0.58 to −0.22)
Deceleration duration (s)	99.53	0.001 (−0.001 to 0.003)	0.990 (0.979 to 1.001)	−0.48 (−0.72 to −0.25)
Braking impulse (N·s)	98.64	−0.650 (−1.677 to 0.377)	1.004 (0.985 to 1.024)	−1.36 (−2.25 to −0.4832)
Deceleration impulse (N·s)	99.76	1.986 (1.126 to 2.847)†	0.970 (0.962 to 0.978)†	−0.80 (−1.08 to −0.51)
Braking RFD (N·s^{-1})	92.05	882.6 (804.1 to 961.1)†	0.321 (0.307 to 0.337)†	−43.1 (−45.6 to −40.6)†
Deceleration RFD (N·s^{-1})	99.93	−17.83 (−45.03 to 9.37)	1.008 (1.004 to 1.013)†	0.5 (0.24 to 0.75)
Avg propulsive power (W)	99.71	−30.97 (−50.79 to −11.16)†	1.030 (1.022 to 1.040)†	1.45 (1.12 to 1.77)
Avg propulsive force (N)	99.99	0.669 (−2.266 to 3.604)	1.002 (0.999 to 1.004)	0.23 (0.18 to 0.28)
Peak propulsive power (W)	99.67	−72.73 (−111.67 to −33.79)†	1.032 (1.021 to 1.042)†	1.06 (0.73 to 1.39)
Peak propulsive force (N)	99.99	−0.241 (−2.283 to 1.801)	1.000 (0.998 to 1.001)	−0.01 (−0.04 to 0.02)
Peak propulsive velocity (m·s^{-1})	98.18	−0.011 (−0.069 to 0.047)	1.014 (0.992 to 1.037)	0.99 (0.68 to 1.3)
Propulsive duration (s)	99.53	−0.001 (−0.004 to 0.002)	1.006 (0.995 to 1.017)	0.19 (0.01 to 0.36)
Propulsive impulse (N·s)	99.65	−1.120 (−3.118 to 0.878)	1.014 (1.004 to 1.024)†	0.82 (0.54 to 1.09)
Propulsive RFD (N·s^{-1})	36.42	2,216 (2,076 to 2,355)†	0.682 (0.597 to 0.777)†	723 (−3,972 to 5,418)†
Peak landing force (N)	99.79	6.42 (−26.47 to 39.31)	1.001 (0.994 to 1.009)	0.29 (−0.08 to 0.67)

*RSI = reactive strength index; Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including “0” and slope as not including “1” OR practically meaningful percent difference of >5%.

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Table 8

Hawkin Dynamics and ForceDecks comparisons (*n* = 132) for countermovement jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
System weight (N)	99.95	9.614 (6.488 to 12.740)†	0.987 (0.983 to 0.991)†	−0.03 (−0.11 to 0.06)
Jump height (cm)	98.31	−0.732 (−1.481 to 0.017)	1.032 (1.009 to 1.056)†	0.72 (0.06 to 1.37)
Flight time (s)	99.58	0.004 (−0.001 to 0.010)	0.996 (0.985 to 1.008)	0.52 (0.33 to 0.71)
Takeoff velocity ($m \cdot s^{-1}$)	98.52	−0.051 (−0.104 to 0.002)	1.025 (1.003 to 1.047)†	0.35 (0.03 to 0.68)
Countermovement depth (cm)	97.85	−0.394 (−1.236 to 0.448)	0.991 (0.967 to 1.017)	0.41 (−0.04 to 0.87)
Modified RSI ($m \cdot s^{-1}$)	96.81	−0.010 (−0.023 to 0.003)	0.949 (0.920 to 0.979)†	−7.64 (−8.7 to −6.57)†
Avg braking power (W)	87.92	310.1 (229.1 to 391.1)†	−2.53 (−2.69 to −2.38)†	−288 (−293 to −283)†
Avg braking force (N)	99.98	12.34 (8.90 to 15.79)†	0.988 (0.986 to 0.991)	−0.18 (−0.26 to −0.1)
Peak braking power (W)	99.88	−17.38 (−25.75 to −9.015)	−0.986 (−0.992 to −0.981)	−200 (−201 to −200)
Peak braking force (N)	99.98	7.67 (3.68 to 11.66)	0.994 (0.992 to 0.996)	−0.09 (−0.15 to −0.03)
Braking duration (s)	99.75	−0.001 (−0.003 to 0.001)	1.006 (0.997 to 1.015)	0.02 (−0.17 to 0.21)
Braking impulse ($N \cdot s$)	99.57	−0.252 (−1.369 to 0.864)	0.995 (0.984 to 1.006)	−0.81 (−1.20 to −0.42)
Braking RFD ($N \cdot s^{-1}$)	99.94	−45.77 (−70.14 to −21.39)†	1.011 (1.007 to 1.015)†	0.02 (−0.2 to 0.23)
Avg propulsive power (W)	99.74	−51.93 (−71.59 to −32.27)†	1.035 (1.026 to 1.044)†	0.69 (0.36 to 1.01)
Avg propulsive force (N)	99.99	−4.799 (−7.045 to −2.540)†	1.008 (1.007 to 1.009)†	0.46 (0.42 to 0.49)
Peak propulsive power (W)	99.72	−109.7 (−146.9 to −72.4)†	1.034 (1.025 to 1.044)†	0.24 (−0.09 to 0.57)
Peak propulsive force (N)	99.99	−0.522 (−2.445 to 1.405)	1.000 (0.999 to 1.001)	−0.02 (−0.05 to 0)
Peak propulsive velocity ($m \cdot s^{-1}$)	98.34	−0.066 (−0.124 to −0.007)†	1.029 (1.006 to 1.052)†	0.23 (−0.09 to 0.54)
Propulsive duration (s)	99.68	0.003 (0.001 to 0.006)†	0.987 (0.978 to 0.997)	−0.1 (−0.25 to 0.05)
Propulsive impulse ($N \cdot s$)	99.75	−4.114 (−5.920 to −2.307)†	1.029 (1.020 to 1.038)†	0.59 (0.34 to 0.84)
Peak landing force (N)	99.99	−1.668 (−9.893 to 6.557)	1.001 (0.999 to 1.003)	0.02 (−0.07 to 0.11)

*RSI = reactive strength index; Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

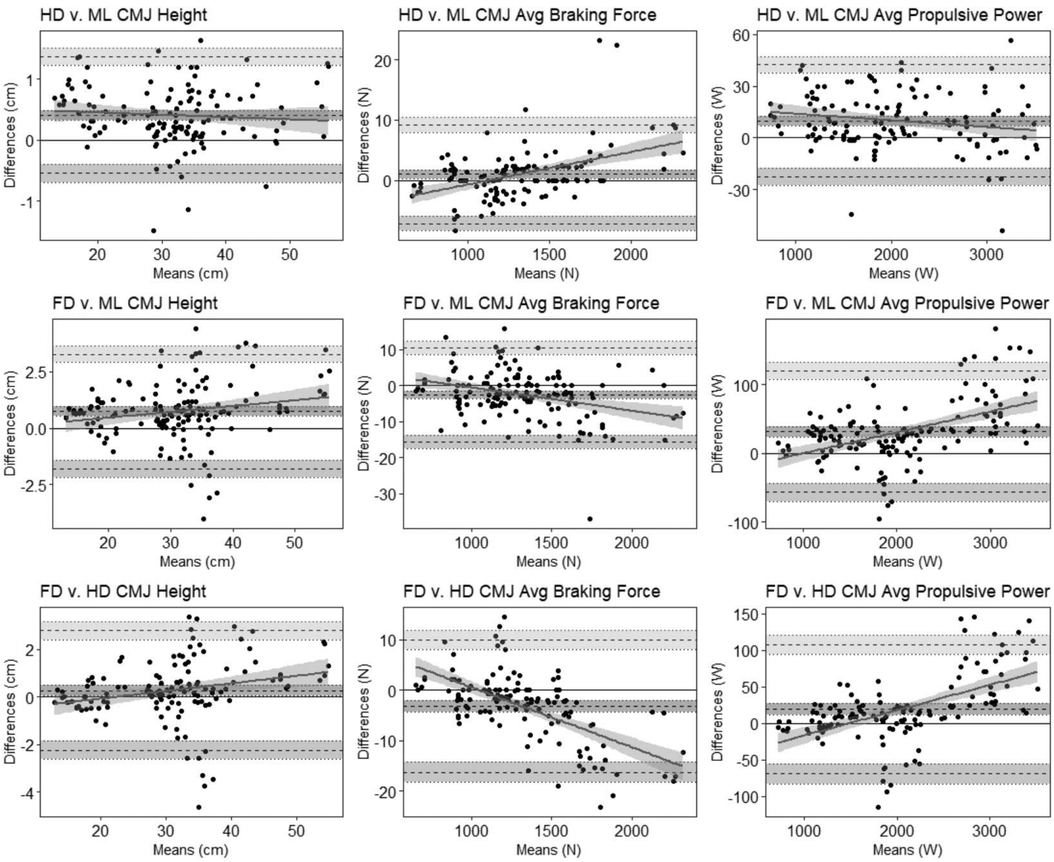

Figure 3. Select comparisons among ForceDecks (FD), Hawkin Dynamics (HD), and custom MATLAB (ML) scripts for analyzing countermovement jump (CMJ) metrics. Each black dot represents a trial where the blue-(or dark gray), green-(or light gray), and red-(or mid gray, lower bound) shaded areas are the respective value and 95% confidence intervals surrounding the mean, upper, and lower 95% confidence interval, respectively. The solid blue (or gray) line with shaded gray area represents the slope and the respective bounds.

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Table 9

MATLAB and Hawkin Dynamics (n = 138) comparisons for drop jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
Jump height (cm)	99.43	−0.251 (−0.596 to 0.094)	1.019 (1.006 to 1.032)†	0.57 (−0.03 to 1.17)
Takeoff velocity (m·s^{-1})	99.22	−0.011 (−0.044 to 0.022)	1.010 (0.995 to 1.025)	0.49 (0.02 to 0.95)
Flight time (s)	99.56	−0.001 (−0.007 to 0.005)	0.999 (0.989 to 1.011)	−0.01 (−0.02 to 0.00)
Contact time (s)	99.99	−0.0002 (−0.001 to −0.000)†	1.000 (1.000 to 1.001)†	−0.20 (−0.38 to −0.02)
Modified RSI (m·s^{-1})	99.37	−0.012 (−0.020 to −0.003)†	1.032 (1.018 to 1.046)†	−0.15 (−0.34 to 0.05)
RSI (AU)	99.92	−0.003 (−0.008 to 0.003)	1.001 (0.996 to 1.006)	0.61 (0.01 to 1.22)
Avg braking power (W)	99.86	−43.78 (−52.16 to −35.40)†	0.977 (0.974 to 0.979)†	−0.68 (−0.79 to −0.57)
Avg braking force (N)	99.94	−0.605 (−8.330 to 7.120)	1.000 (0.996 to 1.004)	−0.07 (−0.20 to 0.07)
Peak braking power (W)	99.87	−105.4 (−145.4 to −65.1)†	0.980 (0.976 to 0.984)†	−0.74 (−0.88 to −0.60)
Peak braking force (N)	99.99	−0.071 (−0.331 to 0.188)	1.000 (0.999 to 1.000)	0.00 (0.00 to 0.00)
Braking phase (s)	99.66	0.001 (−0.001 to 0.003)	0.995 (0.985 to 1.005)	−0.23 (−0.5 to 0.04)
Braking impulse (N·s)	99.93	1.716 (0.642 to 2.789)†	0.994 (0.990 to 0.999)†	0.17 (0.09 to 0.25)
Avg propulsive power (W)	99.78	−34.95 (−51.26 to −18.63)†	1.024 (1.016 to 1.032)†	0.33 (0.03 to 0.63)
Avg propulsive force (N)	99.99	−3.76 (−6.806 to 0.663)	0.999 (0.998 to 1.001)	−0.30 (−0.35 to −0.26)
Peak propulsive power (W)	99.79	−63.23 (−91.37 to −35.09)†	1.029 (1.021 to 1.037)†	0.72 (0.42 to 1.02)
Peak propulsive force (N)	99.99	−6.59 (−10.86 to −2.34)†	1.004 (1.003 to 1.007)†	0.10 (0.05 to 0.15)
Peak propulsive velocity (m·s^{-1})	99.17	−0.008 (−0.044 to 0.027)	1.010 (0.995 to 1.026)	0.65 (0.24 to 1.07)
Propulsive duration (s)	99.32	0.001 (−0.003 to 0.004)	1.003 (0.989 to 1.017)	0.66 (0.29 to 1.04)
Propulsive impulse (N·s)	99.72	−1.373 (−2.988 to 0.242)	1.013 (1.004 to 1.022)†	0.39 (0.01 to 0.76)
Peak landing force (N)	99.94	5.187 (−12.736 to 23.112)	0.999 (0.996 to 1.004)	0.33 (0.03 to 0.63)

*RSI = reactive strength index; Avg = average.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

phase. Doing so will also reduce the influence of signal noise on calculations, which is why a completely still quiet phase of at least 1 second is necessary. Moreover, the MATLAB script used similar drop jump analyses to the commercial software for estimating initial velocity based on box height for more accurate comparisons, but it is likely the actual velocity upon impact varied because of individuals dropping from slightly above or below the actual box height (despite instructions to do their best to drop straight down). Thus, actual drop jump heights are likely vastly different than actual jump heights achieved during the drop jump using this method for calculating impulse-momentum–derived jump heights. Ultimately, data quality is the responsibility of the practitioner or scientist collecting the data and can only be assured, to the best of their ability, if the necessary precautions are taken.

For comparisons between Hawkin Dynamics and MATLAB, there were no systematic errors in squat jump or IMTP metrics, except force at 0 millisecond and peak force for IMTP. Although more metrics displayed systematic errors in the countermovement jump and drop jump, all percent differences for trials between Hawkin Dynamics and MATLAB code demonstrated very low percent errors (<3%). Of note, there was proportional bias for several metrics across the various tests, suggesting that the small errors were influenced by test performances. For example, drop jump height was underestimated by Hawkin Dynamics compared with MATLAB at higher jump heights according to the proportional bias and Bland-Altman plots. Also, despite the difference being systematic, the IMTP peak force was within 1 N between Hawkin Dynamics and MATLAB, making this metric closely in agreement between devices for IMTP. However, the small differences in identifying the initiation of movement between Hawkin Dynamics and MATLAB were enough to elicit small systematic differences (−27.60 N; <1%) in forces at the starting point for the IMTP (forces at 0 millisecond), which would carry throughout the identification of subsequent landmarks. This concept also explains small errors in jump testing because subtle differences in landmark occurrences would shift start and end points for phases and subsequently alter phasic metrics' values. Nonetheless, there were minor differences between Hawkin Dynamics' and MATLAB's analyses procedures, which may still cause trivial discrepancies of force-time metric comparisons.

Considering the subtle differences between MATLAB and Hawkin Dynamics analyses, errors between ForceDecks and MATLAB were mostly similar for ForceDecks to Hawkin Dynamics comparisons. ForceDecks analysis differed mostly from the initiation of movement landmark thresholds, which, along with the determination of system weight (43), has previously been found to affect various calculations (e.g., integration, jump height) (9,39). To limit premature identifications, the first landmark of movement was identified by Hawkin Dynamics and MATLAB as 5 *SD* of weighing phase's vGRFs, which was then backtracked to system weight or within 1 *SD* of system weight, respectively. Meanwhile, in accordance with their user manual, the ForceDecks software uses "an 20 N threshold." Differences in landmark identifications likely caused discrepancies in the present data (lower associations, higher relative errors) in squat jump's propulsive duration and RFD. However, identification of movement initiation errors is an implausible influence on countermovement jump's eccentric phase comparisons because eccentric subphases (i.e., deceleration or braking phase) begin beyond the initiation of movement (i.e., point of minimum force or peak eccentric velocity). Of note, IMTP was the most seemingly affected by the initiation of movement identification errors (5% error of force at 0 millisecond), with systematic or proportional bias for all metrics except RFD from 0 to 250 milliseconds for agreement between ForceDecks and Hawkin Dynamics and MATLAB and Force at 100 and 200 milliseconds for agreement between ForceDecks and MATLAB. Although percent errors were lower for later time bands (i.e., force at 150 and 200 milliseconds and RFD from 0 to 250 milliseconds), the error may be practically meaningful and should be compared across devices with caution. Of note, according to the ForceDecks user manual, the IMTP's start of movement is defined as "when exercise commences." We assumed this was the same 20 N threshold as jump testing. Still,

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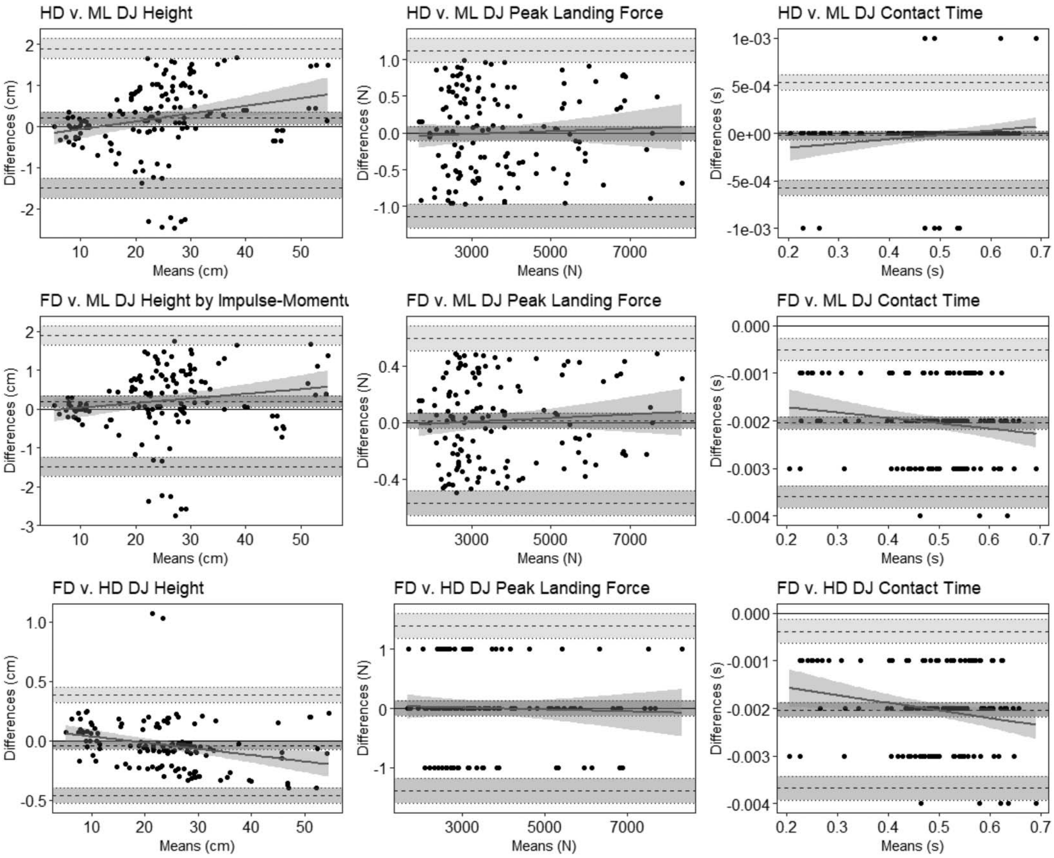

Figure 4. Select comparisons among ForceDecks (FD), Hawkin Dynamics (HD), and custom MATLAB (ML) scripts for analyzing drop jump (DJ) metrics. Each black dot represents a trial where the blue-(or dark gray), green-(or light gray), and red-(or mid gray, lower bound) shaded areas are the respective value and 95% confidence intervals surrounding the mean, upper, and lower 95% confidence interval, respectively. The solid blue (or gray) line with shaded gray area represents the slope and the respective bounds.

Table 10

MATLAB and ForceDecks (*n* = 138) comparisons for drop jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
Jump height (cm)	97.84	−0.092 (−0.449 to 0.267)	1.001 (0.998 to 1.030)	0.74 (0.17 to 1.32)
Jump height flight time (cm)	99.74	0.234 (−0.052 to 0.519)	0.999 (0.990 to 1.008)	0.75 (0.47 to 1.03)
Takeoff velocity ($m\cdot s^{-1}$)	99.74	−0.001 (−0.055 to 0.054)	1.000 (0.975 to 1.025)	0.37 (0.08 to 0.66)
Flight time (s)	99.76	0.005 (0.001 to 0.009)†	0.994 (0.985 to 1.002)	−0.44 (−0.47 to −0.4)
Contraction time (s)	99.96	−0.002 (−0.003 to −0.001)†	1.001 (0.997 to 1.004)	0.35 (0.21 to 0.49)
Countermovement depth (cm)	99.11	0.084 (−0.584 to 0.753)	0.993 (0.977 to 1.009)	−0.90 (−1.44 to −0.36)
RSI (AU)	99.88	−0.003 (−0.010 to 0.003)	1.009 (1.004 to 1.015)†	0.72 (0.5 to 0.93)
Modified RSI ($m\cdot s^{-1}$)	99.82	−0.001 (−0.007 to 0.004)	1.011 (1.004 to 1.018)†	1.03 (0.7 to 1.36)
Avg eccentric force (N)	99.93	−13.09 (−21.73 to −4.46)†	1.013 (1.009 to 1.018)†	0.50 (0.36 to 0.64)
Peak eccentric force (N)	99.99	−0.037 (−0.171 to 0.097)	1.000 (0.999 to 1.000)	0.00 (0.00 to 0.00)
Eccentric duration (s)	0.006	0.390 (0.363 to 0.417)†	0.994 (0.991 to 0.997)†	58.3 (45.3 to 71.3)†
Eccentric impulse (N·s)	99.94	1.970 (0.908 to 3.031)†	0.997 (0.993 to 1.002)	0.57 (0.49 to 0.65)
Drop landing RFD ($N\cdot s^{-1}$)	84.52	2,037 (−5,017 to 9,092)	0.974 (0.912 to 1.041)	1.97 (0.61 to 3.40)
Avg propulsive power (W)	93.44	−549.8 (−661.3 to −438.3)†	0.377 (0.361 to 0.394)†	−71.7 (−72.5 to −71.0)†
Avg propulsive force (N)	99.96	−3.297 (−0.482 to 1.888)	1.004 (1.001 to 1.008)†	0.26 (0.21 to 0.32)
Peak propulsive power (W)	87.52	−547.5 (−794.4 to −300.7)†	0.457 (0.431 to 0.485)†	−61.7 (−62.7 to −60.7)†
Peak propulsive force (N)	99.50	12.76 (−13.51 to 39.03)	0.977 (0.965 to 0.989)	−1.52 (−1.93 to −1.12)
Peak propulsive velocity ($m\cdot s^{-1}$)	99.45	−0.027 (−0.056 to 0.003)	1.015 (1.002 to 1.028)†	0.26 (−0.01 to 0.54)
Propulsive impulse (N·s)	99.84	−0.865 (−2.122 to 0.391)	1.010 (1.003 to 1.017)†	0.39 (0.15 to 0.62)
Peak landing force (N)	99.99	−0.032 (−0.161 to 0.097)	1.000 (0.990 to 1.000)	0.00 (0.00 to 0.00)

*RSI = reactive strength index; Avg = average; RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

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Table 11

Hawkin Dynamics and ForceDecks (n = 131) comparisons for drop jump force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
Jump height (cm)	99.97	0.086 (−0.001 to 0.172)	0.995 (0.992 to 0.998)†	−0.02 (−0.21 to 0.17)
Takeoff velocity (m·s^{-1})	98.87	0.002 (−0.038 to 0.041)	0.994 (0.977 to 1.013)	−0.05 (−0.13 to 0.04)
Flight time (s)	99.77	0.006 (0.001 to 0.010)†	0.993(0.985 to 1.002)	−0.43 (−0.47 to −0.39)
Contraction time (s)	99.99	−0.001 (−0.001 to −0.001)†	0.998 (0.997 to 0.999)†	0.57 (0.40 to 0.74)
Modified RSI (m·s^{-1})	94.46	−0.079 (−0.107 to −0.052)†	0.886 (0.851 to 0.923)†	−25.7 (−28.0 to −23.5)†
RSI (AU)	99.86	−0.001 (−0.008 to 0.008)	1.008 (1.002 to 1.014)†	0.91 (0.65 to 1.16)
Avg braking force (N)	99.99	−13.46 (−16.84 to −10.07)†	1.014 (1.012 to 1.016)†	0.60 (0.55 to 0.65)
Peak braking force (N)	99.99	0.032 (−0.288 to 0.353)	0.999 (0.999 to 1.001)	0.00 (0.00 to 0.01)
Braking duration (s)	0.003	0.399 (0.370 to 0.429)†	−0.826 (−0.980 to −0.697)†	59.3 (46.2 to 74.2)†
Braking impulse (N·s)	99.99	−0.085 (−0.597 to 0.427)	1.005 (1.002 to 1.007)†	0.42 (0.38 to 0.46)
Avg propulsive power (W)	93.72	−528.9 (−638.5 to −419.5)†	0.370 (0.355 to 0.387)†	−71.9 (−72.6 to −71.2)†
Avg propulsive force (N)	99.98	1.65 (−2.45 to 5.75)	1.004 (1.001 to 1.007)†	0.56 (0.51 to 0.62)
Peak propulsive power (W)	99.72	−486.8 (−729.4 to −244.2)†	0.443 (0.417 to 0.471)†	−62.0 (−63.0 to −61.1)†
Peak propulsive force (N)	99.45	18.73 (−8.92 to 46.38)	0.973 (0.960 to 0.986)	−1.63 (−2.05 to −1.22)
Peak propulsive velocity (m·s^{-1})	98.71	−0.009 (−0.054 to 0.036)	0.997 (0.978 to 1.017)	−0.33 (−0.38 to −0.29)
Propulsive impulse (N·s)	99.98	1.142 (0.660 to 1.623)†	0.993 (0.990 to 0.995)†	0.03 (−0.08 to 0.15)
Peak landing force (N)	99.95	−5.20 (−23.38 to 12.98)	1.000 (0.996 to 1.004)	−0.10 (−0.25 to 0.06)

*RSI = reactive strength index; Avg = average.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

peak force for the IMTP was within 1 N differences across all trials measured by all analyses.

Landmark identification errors may also stem from small disagreements in system weight estimations. Thus, some of the ForceDecks discrepancies may also be subject to the current collection procedures, which used the ForceDecks Jump application. This application permits high throughputs of data collection in short durations by analyzing multiple trials across multiple force plates simultaneously (i.e., using 1 machine to concurrently operate multiple force plates). However, the application measures system weight before all trials being conducted, which provides the same system weight for all trials of the testing battery. Meanwhile, Hawkin Dynamics and MATLAB processes system weight for the first 1 second of data collection leading up to the initiation of movement for each trial, which accounts for any subtle changes in vGRFs between trials. This problem is most apparent for IMTP testing because the pretension elicited while determining system weight at the start of the assessment is difficult to precisely repeat across trials. System weight errors can also stem from signal noise, which can be reduced by having individuals be as still as possible before initiating movement for at least 1 second. Ultimately, it is fundamentally critical to testing data quality and comparisons across devices that the same procedures are followed because a 0.5% error in system weight elicits remarkable errors in jump height calculations, landmark identification, integration techniques, and subsequent inferences from data analysis (43).

As mentioned previously, the braking phase in Hawkin Dynamics is matched with the deceleration phase in ForceDecks (Table 1) thereby making any other comparisons invalid. For example, Hawkin Dynamics braking phase power outputs were vastly different than the eccentric power metrics of ForceDecks because these would include the entire eccentric phase (negative velocity from the initiation of movement until velocity reaches 0 m·s^{-1}). Comparisons must also be made across analogous definitions, as well as corresponding calculations. For example, there are numerous ways to calculate RFD, including average RFD (average slope between 2 arbitrary time points or peak force divided by time to reach peak force), RFD across time bands from the initiation of movement (0–200 milliseconds), or peak RFD (differentiation to compute an instantaneously highest RFD achieved). Regardless of similarities in RFD definitions ("RFD over the propulsive phase"), calculation discrepancies across software likely exist and provide rationale for RFD metric inconsistencies (6,14). When comparing Hawkin Dynamics and

Table 12

MATLAB and Hawkin Dynamics (n = 130) comparisons for isometric mid-thigh pull force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
Peak force (N)	1.00	−0.57 (−1.12 to −0.02)†	1.000 (1.000 to 1.000)	0.03 (−0.04 to 0.1)
Time to peak force (s)	99.35	0.01 (−0.04 to 0.07)	0.988 (0.968 to 1.001)	1.78 (0.93 to 2.62)
Force at 0 millisecond (N)	99.22	−27.60 (−49.37 to −5.82)†	1.041 (1.018 to 1.065)†	−0.03 (−0.85 to 0.79)
Force at 50 milliseconds (N)	96.86	−15.02 (−71.02 to 40.97)	1.024 (0.980 to 1.071)	0.13 (−0.98 to 1.24)
Force at 100 milliseconds (N)	98.41	19.60 (−27.42 to 66.62)	1.002 (0.970 to 1.034)	−0.11 (−1.28 to 1.07)
Force at 150 milliseconds (N)	98.72	5.87 (−44.85 to 56.60)	1.012 (0.983 to 1.041)	0.33 (−0.67 to 1.32)
Force at 200 milliseconds (N)	97.57	26.91 (−51.09 to 104.91)	0.994 (0.956 to 1.034)	0.58 (−0.36 to 1.52)
Force at 250 milliseconds (N)	98.94	20.97 (−34.29 to 76.23)	0.994 (0.969 to 1.020)	0.42 (−0.52 to 1.28)
RFD from 0 to 50 milliseconds (N·s^{-1})	93.90	−22.86 (−430.04 to 384.32)	1.019 (0.958 to 1.084)	5.14 (−2.14 to 12.42)†
RFD from 0 to 100 milliseconds (N·s^{-1})	97.72	181.68 (−34.32 to 397.69)	0.987 (0.950 to 1.025)	4.51 (0 to 9.03)
RFD from 0 to 150 milliseconds (N·s^{-1})	97.88	89.86 (−119.44 to 299.17)	0.999 (0.963 to 1.036)	4.07 (0.26 to 7.87)
RFD from 0 to 250 milliseconds (N·s^{-1})	98.62	62.23 (−79.60 to 204.06)	0.989 (0.960 to 1.018)	2.96 (0.91 to 5.01)

*RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

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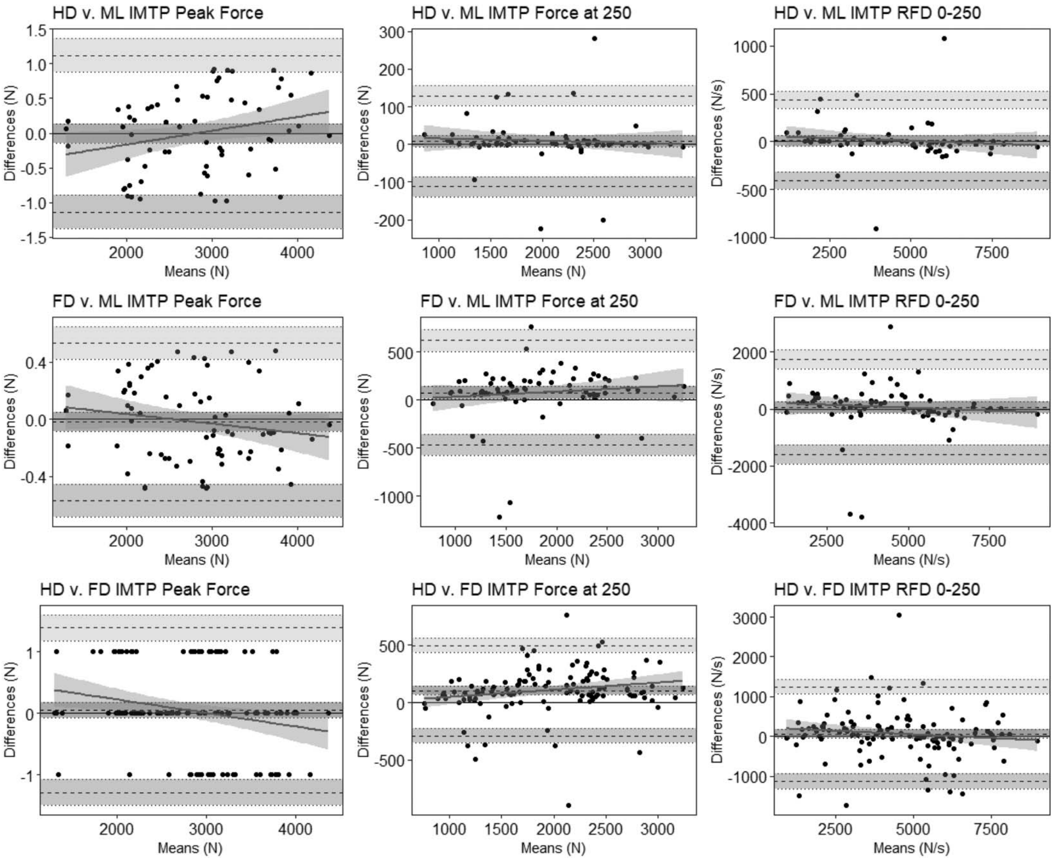

Figure 5. Select comparisons among ForceDecks (FD), Hawkin Dynamics (HD), and custom MATLAB (ML) scripts for analyzing isometric mid-thigh pull (IMTP) metrics. Each black dot represents a trial where the blue-(or dark gray), green-(or light gray), and red-(or mid gray, lower bound) shaded areas are the respective value and 95% confidence intervals surrounding the mean, upper, and lower 95% confidence interval, respectively. The solid blue (or gray) line with shaded gray area represents the slope and the respective bounds.

ForceDecks, there was no systematic or proportional bias unlike comparisons of Hawkin Dynamics and ForceDecks to MATLAB for squat jump propulsive RFD. For the MATLAB calculation, propulsive RFD was determined as the change in vGRF divided by the duration from movement initiation to the point of peak takeoff force, whereas calculations for Hawkin Dynamics and ForceDecks are uncertain. Interestingly, the same errors were noted for drop jump's drop landing RFD but not for countermovement jump's braking or deceleration phase RFD. Finally , it is best to ignore propulsive RFD, as noted in Hawkin Dynamics metric output, for countermovement jump because this resulted in very poor agreement (R^2 = 36%; average error = 723%) for ForceDecks to MATLAB. Due to these complications, it is suggested that RFD metrics be used with extreme caution, considering that only braking phase RFD shows the most promise for comparisons across software.

Jump height may also be calculated in many ways, providing variations in results (21). The impulse-momentum theorem is the

Table 13

MATLAB and ForceDecks (*n* = 139) comparisons for isometric mid-thigh pull force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
Peak force (N)	99.99	0.17 (−0.10 to 0.44)	1.000 (0.999 to 1.000)	0.00 (0.00 to 0.00)
Time to peak force (s)	99.72	−0.02 (−0.06 to 0.01)	1.002 (0.989 to 1.015)	−0.95 (−1.47 to −0.43)
Force at 0 millisecond (N)	60.97	206.1 (93.9 to 318.4)†	0.797 (0.686 to 0.925)†	4.12 (2 to 6.24)
Force at 50 milliseconds (N)	69.84	−81.22 (−251.72 to 89.28)	1.225 (1.074 to 1.397)†	10.1 (7.5 to 12.7)†
Force at 100 milliseconds (N)	78.12	12.15 (−150.59 to 174.90)	1.077 (0.963 to 1.205)	14.7 (11.6 to 17.7)†
Force at 150 milliseconds (N)	75.66	−88.90 (−305.50 to 127.70)	1.134 (1.008 to 1.276)†	8.47 (5.92 to 11.01)†
Force at 200 milliseconds (N)	79.27	−16.85 (−234.24 to 200.53)	1.053 (0.944 to 1.174)	5.23 (2.95 to 7.51)†
RFD from 0 to 50 milliseconds (N·s^{-1})	75.18	−642.8 (−1,445.9 to 160.2)	2.474 (2.196 to 2.788)†	118 (95.8 to 140.3)†
RFD from 0 to 100 milliseconds (N·s^{-1})	78.04	219.2 (−383.8 to 822.2)	1.180 (1.055 to 1.320)†	36.3 (27.3 to 45.2)†
RFD from 0 to 150 milliseconds (N·s^{-1})	75.37	−149.4 (−831.8 to 532.9)	1.188 (1.054 to 1.337)†	19.6 (14.2 to 24.9)†
RFD from 0 to 250 milliseconds (N·s^{-1})	80.36	260.32 (−49.69 to 570.33)	0.955 (0.894 to 1.021)	11.8 (7.1 to 16.4)†

*RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

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Table 14

Hawkin dynamics and ForceDecks (*n* = 121) comparisons for isometric mid-thigh pull force-time metrics.*

Force-time metric	R^2	Intercept	Slope	% Difference
Peak force (N)	99.99	0.66 (0.18 to 1.15)†	0.999 (0.999 to 0.999)†	0.00 (0.00 to 0.01)
Time to peak force (s)	99.14	−0.074 (−0.120 to −0.029)†	1.012 (0.995 to 1.029)	−3.60 (−5.32 to −1.87)
Force at 0 millisecond (N)	62.94	145.8 (−45.65 to 245.9)	0.880 (0.781 to 0.991)†	5.03 (2.67 to 7.38)†
Force at 50 milliseconds (N)	62.94	−139.92 (−294.60 to 14.77)	1.299 (1.163 to 1.450)†	11.2 (8.4 to 14.1)†
Force at 100 milliseconds (N)	78.46	67.58 (−203.17 to 68.01)	1.161 (1.067 to 1.263)†	16.5 (13.1 to 19.9)†
Force at 150 milliseconds (N)	83.25	88.96 (−232.26 to 54.33)	1.152 (1.070 to 1.241)†	9.69 (7.16 to 12.22)†
Force at 200 milliseconds (N)	90.32	−13.11 (−130.80 to 104.58)	1.063 (1.005 to 1.125)†	5.91 (3.94 to 7.87)†
RFD from 0 to 50 milliseconds ($N\cdot s^{-1}$)	71.85	−212.4 (−856.4 to 431.6)	2.333 (2.119 to 2.568)†	138 (110 to 165)†
RFD from 0 to 100 milliseconds ($N\cdot s^{-1}$)	80.53	312.3 (−153.9 to 778.5)	1.207 (1.114 to 1.308)†	38.3 (27.6 to 48.9)†
RFD from 0 to 150 milliseconds ($N\cdot s^{-1}$)	88.04	101.5 (−271.6 to 474.5)	1.160 (1.090 to 1.235)†	20.7 (15.1 to 26.3)†
RFD from 0 to 250 milliseconds ($N\cdot s^{-1}$)	91.00	216.78 (−44.16 to 478.05)	0.965 (0.914 to 1.020)	4.00 (0.40 to 7.60)

*RFD = rate of force development.

†Statistical significance for intercept as not including "0" and slope as not including "1" OR practically meaningful percent difference of >5%.

recommended method for estimating jump height as half of takeoff velocity squared divided by gravitational acceleration (9.81 $m\cdot s^{-2}$), which requires integrating the force-time curve (21,43). Thus, integration errors would lead to error in jump height calculations via impulse-momentum theorem. Another common method to calculating jump height is via flight time, which can be altered through either human or software errors (36). The Hawkin Dynamics software solely uses the impulse-momentum method, whereas ForceDecks provides both jump height calculations. However, drop jump modified RSI (jump height divided by contact time) for ForceDecks is calculated with jump height via flight time, which resulted in low agreement with Hawkin Dynamics modified RSI. On the other hand, RSI is a ratio of flight time divided by contact time making agreements stronger across devices according to the current findings. Finally, despite limited systematic differences across integration-derived countermovement jump metrics (e.g., takeoff velocity, peak velocity, and countermovement depth), practically notable overestimation errors occurred for ForceDecks estimations of average and peak deceleration power (−192 to −288%). These errors persisted across drop jump ForceDecks analyses with drop duration not aligning with eccentric or braking durations and errors in average concentric power (~−72%) and peak concentric power (~−62%). Reasons for the error in power calculations are unclear at this time. The aforementioned errors would suggest that these metrics (see Table 2 for exact naming criteria) should not be used interchangeably across these devices.

The current investigation sought to examine variations between force-time analysis strategies derived from single-session testing, but future research should aim to identify whether potential longitudinal implementation of commercial force plate software yield similar trends in data over time (i.e., reliability). Although the software might vary in direct numeric comparisons of select force-time metrics, the changes in these metrics over time (e.g., because of training adaptations/maladaptation) might be similar across software analysis techniques. Thus, future research in this direction will help identify if varying software techniques are similarly sensitive to changes in performances, providing insight into whether practitioner decision making may differ based on software used. Additionally, when practitioners transition from one software program to another, it is pertinent that they become aware of any differences in analyses, definitions of phases within a movement, and calculations for given metrics. Otherwise, comparisons from historical data to current data with new analysis techniques may lead to incorrect decisions being made from inaccurate data (i.e., comparing differently calculated jump heights or defined braking phases). Still, it is the scientists' and practitioners' responsibility to ensure that the data they are collecting are of high quality by following appropriate data collection guidelines (which may be slightly different across manufacturers) and confirming the quality of all data they are including in their analyses.

Practical Applications

Regardless of the automated analysis strategy, the MATLAB scripts provided from the current study (see Supplemental Digital Contents 1–4 for squat jump, countermovement jump, drop jump, and IMTP, respectively, http://links.lww.com/JSCR/A328), Vald ForceDecks or Hawkin Dynamics, it is important to implement error checking via visual inspection of landmark identifications on force-time curves. If landmarks do not seem to be correctly identified, it is best to remove those trials from further analyses because subsequent calculations of force-time metrics will be prone to large errors, which lends to faulty decision making in the training and recovery processes of high performers.

Overall, Hawkin Dynamics showed small errors with the MATLAB script used in the current study, likely because of the similarities in analysis techniques deployed among procedures as discussed above. However, ForceDecks analyses demonstrated more differences in landmark identification thresholds, metric definitions, and calculations. Thus, it is important to be aware of the differences outlined in the current article, namely, across RFD and power calculations, before making any comparisons across devices. Ultimately, the most important factor when comparing across analyses is the definition of the phase and metric being analyzed. For example, the braking phase definition in Hawkin Dynamics matches the deceleration phase in ForceDecks, making these direct comparisons the only valid comparisons across these software analyses for the eccentric phase. In conclusion, comparing results across software analyses should be used with extreme caution by only selecting metrics that met the agreement qualifications for each test provided in the current article.

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