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SAMPLING FREQUENCY IMPACT ON COUNTERMOVEMENT JUMP METRICS

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ABSTRACT

Purpose: Sampling frequency is a methodological consideration that can influence force-time data outcomes and calculations. The purpose of this investigation was to examine differences in countermovement jump performance from data obtained at three different sampling frequencies. *Methods:* 85 recreationally trained individuals performed 3 jump trials on a dual-force plate, sampled at 2400 Hz. Each trial was then resampled to 1200 and 600 Hz. *Results:* Repeated-measures ANOVA revealed no statistically significant differences in sampling frequencies. Pearson's product moment correlations revealed significant moderate to very large ($r = .47 - .75$) between 600 and 2400 Hz and large to very large relationships between 600 and 1200 Hz ($r = .5 - .76$). Significant large to near perfect relationships were seen between 1200 and 2400 Hz ($r = .87 - .99$). *Conclusions:* Though no variables demonstrated statistically significant differences, the stronger relationships and higher levels of agreement between 1200 and 2400 Hz, suggest that a minimum of 1000 Hz be used when collecting force-time data during the countermovement jump.

Keywords: Force-Time Analysis, Countermovement Jump, Methodology, Sampling Frequency

INTRODUCTION

A critical component in the decision-making process when designing training programs to aid an athlete's physical development and/or preparation is understanding the athlete's current capabilities. A variety of different assessments can be used in this process, but one of the most common is the countermovement vertical jump (CMJ) (Bishop et al., 2022; Gathercole et al., 2015; Taylor et al., 2012; Thorpe et al., 2017). This assessment is typically used for its ease of implementation, with a minimal familiarization period, and does not induce additional fatigue in the athlete (Donahue et al., 2023; Gathercole et al., 2015; McMahon, Lake, et al., 2018; Suchomel & Bailey, 2014).

As with any assessment, the protocol im-

plemented can significantly influence the results. Previous investigations have examined elements of the protocol, from the use of arm swings and countermovement depth to the verbal instructions given to the participant (McInnis & Donahue, 2024; Pérez-Castilla et al., 2021; Sánchez-Sixto et al., 2024; Young et al., 1995). Additionally, special attention has been paid to the equipment being used during the assessment, and factors inside the equipment, such as sampling frequency (Cronin et al., 2004; García-Ramos et al., 2016; Hori et al., 2009; Merrigan et al., 2024; Street et al., 2001). When using different pieces of equipment, such as linear position transducers, force plates, and wearable technology (accelerometers and in-soles) to measure CMJ performance, the sam-

pling frequency of each device can easily account for any observed differences. Currently, the force plate is considered the gold-standard method for assessing CMJ performance. This is due primarily to the data's reliability and the large number of variables that can be calculated to develop the best possible understanding of performance. Although differences in sampling frequencies are commonly discussed in comparing findings across technologies, there is a general lack of evidence examining the influence of sampling frequency within a measurement tool, such as the force plate. Previous investigations found that sampling frequency impacted jump height calculations, with underestimations occurring at frequencies below 1000 Hz (Street et al., 2001). This led to the initial recommendation of using sampling frequencies above 1000 Hz when assessing CMJ performance on a force platform (Street et al., 2001). Reliability of several CMJ-derived variables, such as force, velocity, power, and temporal metrics, at sampling frequencies from 25 to 500 Hz was examined, and it was recommended that 200 Hz be used in the assessment of CMJ performance (Hori et al., 2009). More recently, a review of methodologies used in ballistic assessment in sports recommended using sampling frequencies between 1000 and 1500 Hz in the vertical jump when using rate-dependent variables (McMaster et al., 2014). These different recommendations can create confusion for researchers and practitioners alike, as each study used different variables, sampling frequencies, and statistical analyses.

As technological advances have progressed, portable equipment that was once limited in sampling frequency can now achieve sampling frequencies comparable to equipment that was traditionally more expensive and permanently fixed in a laboratory. As such, it is important to examine how sampling frequency can affect the variables measured by the CMJ that athletes

perform on a routine basis. Thus, this investigation examined CMJ performance across three sampling frequencies (600, 1200, and 2400 Hz) using a repeated-measures design. Additionally, the study sought to examine the relationship between data obtained at each sampling frequency and the agreement between sampling frequencies. We hypothesize that the 600 Hz sampling frequency would produce different values across all jump-related metrics compared with the 1200 and 2400 Hz frequencies. Additionally, we hypothesize that the 600 Hz frequency will produce a systematic bias across all variables compared to the other two frequencies.

METHODS

Experimental Design

An observational cross-sectional research design was used to assess the impact of three force-time sampling frequencies during CMJ assessment in a single testing session. To determine the differences between sampling frequencies, with an alpha level of 0.05, a power of 80%, and an effect size f of 0.25, a minimum sample size of 28 participants was required. To determine the relationship between calculated metrics at each frequency, using an alpha level of 0.05, statistical power of 80%, and an r value of 0.30, a minimum of 84 participants were required. Sample size estimations were performed using G*Power (Version 3.1, University of Düsseldorf, Germany).

Participants

85 recreational active college-aged participants completed this investigation (43 males and 42 females) (age 19.96 ± 0.83 years, height 173.8 ± 5.75 cm, body mass 78.28 ± 7.73 kg). All participants self-reported engaging in physical activity at least twice per week for the six months and were free of lower-extremity injury for the 12 months prior to data collection. Additionally, participants completed the Physical Activity

Readiness Questionnaire prior to data collection. Once all inclusion criteria were met, participants provided informed written consent, as approved by the University of Southern Mississippi's institutional review board (IRB# 22-1162).

Procedures

Each participant completed a standardized warm-up prior to data collection. This warmup included dynamic lower-body movements such as jumping jacks, knee hugs, leg swings, and body-weight squats. Participants then completed at least 3 submaximal CMJ trials. Once the warmup was completed, participants stood with each foot placed on dual force plates on the laboratory floor (AMTI, Watertown, MA, USA). A dowel rod was placed on the participant's back to ensure an arm swing was not used. During each trial, participants were allowed to use a self-selected stance as long as each foot remained on the force plate during the jumping tasks and a self-selected depth during the countermovement (Donahue et al., 2023; McMahan et al., 2022; McMahan, Lake, et al., 2018). Prior to the initiation of each trial, participants were given the instructions to "jump with a maximal effort." Each trial was separated by a 30-second interval. A total of three successful trials were collected for each participant. As this investigation aimed to examine the agreement between variables when sampled at different frequencies, each trial was used as its own observation. In total, 255 individual trials were used in this analysis.

Data Analysis

Ground reaction force data were sampled at 2400 Hz. Raw data for each trial were then resampled at 1200 and 600 Hz. Raw data for each trial and each frequency were then analyzed using a customized MATLAB script (MathWorks Inc., Natick, MA, USA). The force-time data was broken into four phases (weighing, un-

weighing, braking, and propulsive) (McMahon, Suchomel, et al., 2018). Body mass was calculated during the weighing phase by averaging the force over 1 s of quiet standing. Movement initiation was determined using the 5SD method. Movement initiation began at the start of the unweighing phase. This phase concluded when force data returned to the measured body mass of the weighing phase. The braking phase was defined as the transition from the unweighing phase to the point at which the vertical center-of-mass velocity crossed zero. The propulsive phase began at the end of the braking phase and concluded at the point of takeoff. Takeoff was identified as the first sample in which force data fell below 10 N.

The variables of interest for this particular study were jump height, time to takeoff (TTT), RSImod, peak and mean phase-specific force, and phase duration. Jump height was calculated using the impulse-momentum method. TTT was calculated as the time from movement initiation to takeoff. RSImod was calculated as the ratio of jump height and TTT.

Statistical Analysis

Each variable of interest was found to be normally distributed using the Shapiro-Wilk test. A repeated-measures analysis of variance was performed to determine whether differences in mean values within each variable were present across sampling frequencies. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied to the degrees of freedom. If significant differences were present, a Fisher's least significant difference test was performed. Eta squared effect sizes were calculated for each variable of interest in the ANOVA. Effect sizes were interpreted as trivial (<0.01), small (0.01 – 0.06), moderate (0.06 – 0.14), and large (>0.14). An alpha level of 0.05 was used in all analyses. Bland-Altman plots were also created to demonstrate

differences in sampling frequencies. Finally, Pearson product-moment correlations were calculated to determine the relationship between variables calculated at each frequency. Correlation coefficients were interpreted as trivial (<0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9), and nearly perfect (> 0.9) (Hopkins, 2002). All

statistical analyses were performed in SPSS (version 28.0, IBM, Armonk, NY).

RESULTS

No statistically significant differences were observed in sampling frequencies across any of the variables of interest. Additionally, all variables demonstrated no meaningful effect sizes.

Table 1. Comparison of Jump Metrics

	600 Hz	1200 Hz	2400 Hz	p	η^2
Jump Height (m)	0.27 ± 0.11	0.27 ± 0.11	0.27 ± 0.11	.53	.002
Time to Takeoff (s)	0.976 ± 0.22	0.991 ± 0.22	0.979 ± 0.23	.25	.005
RSImod	0.30 ± 0.15	0.30 ± 0.15	0.30 ± 0.15	.80	< .001
Peak Braking Force (N)	882.86 ± 377.0	887.66 ± 380.83	887.51 ± 380.60	.83	< .001
Mean Braking Force (N)	441.87 ± 208.55	444.27 ± 214.48	443.86 ± 214.30	.85	< .001
Braking Duration (s)	0.218 ± 0.09	0.221 ± 0.09	0.218 ± 0.09	.54	.002
Peak Propulsive Force (N)	974.6 ± 365.6	978.85 ± 369.31	979.36 ± 369.39	.83	< .001
Mean Propulsive Force (N)	600.68 ± 229.73	605.02 ± 237.65	607.93 ± 238.24	.63	.001
Propulsive Duration (s)	0.316 ± 0.07	0.318 ± 0.07	0.314 ± 0.07	.47	.003

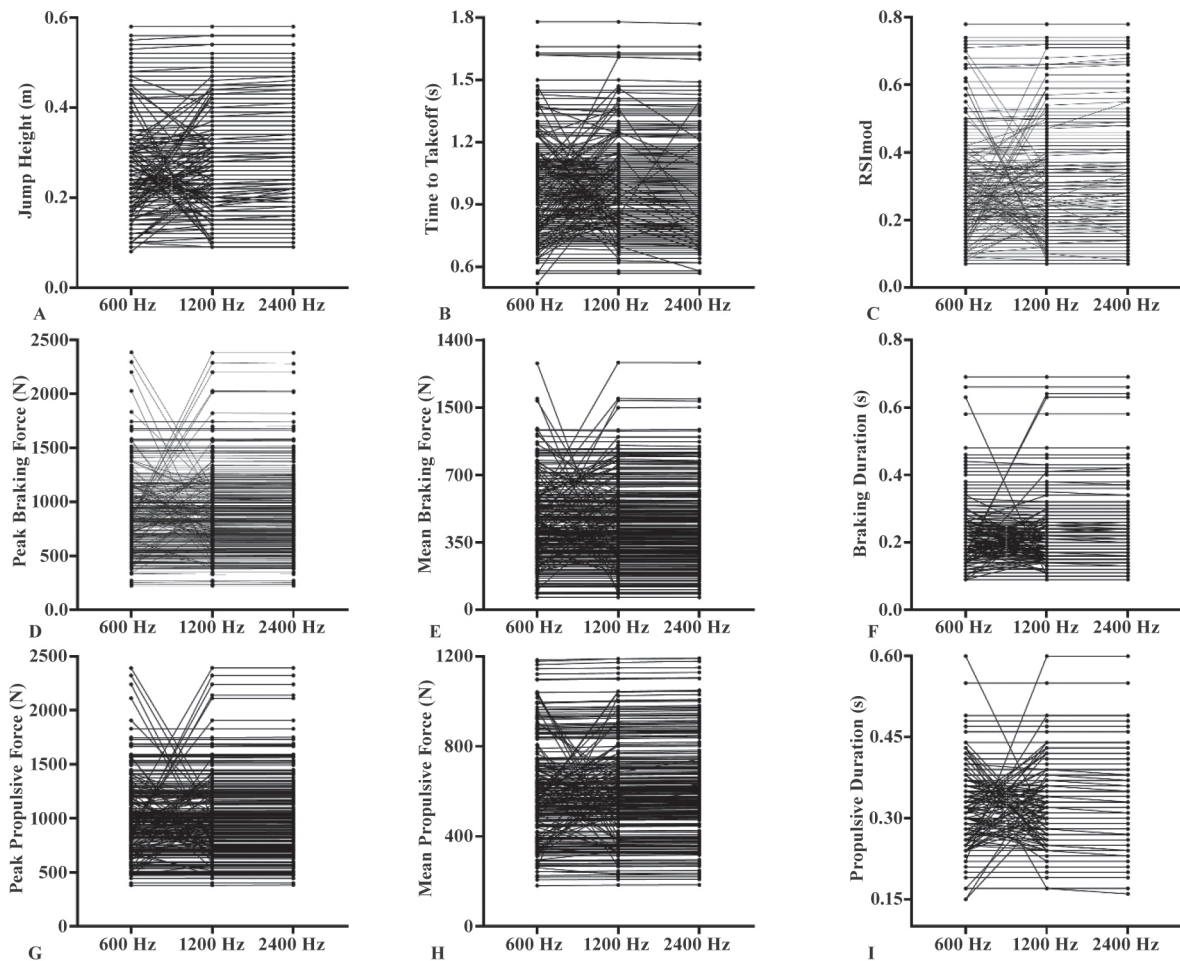


Figure 1. Individual Trial Comparisons Across Sampling Frequencies. A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration

Statistically significant relationships were seen between the 600 Hz and 1200 Hz sampling rates for all nine variables of interest ($r = .50 - .75$). Statistically significant relationships were seen between 600 Hz and 2400 Hz

all nine variables of interest ($r = .47 - .75$). Statistically significant relationships were seen between 1200 Hz and 2400 Hz for all nine variables ($r = .88 - .99$).

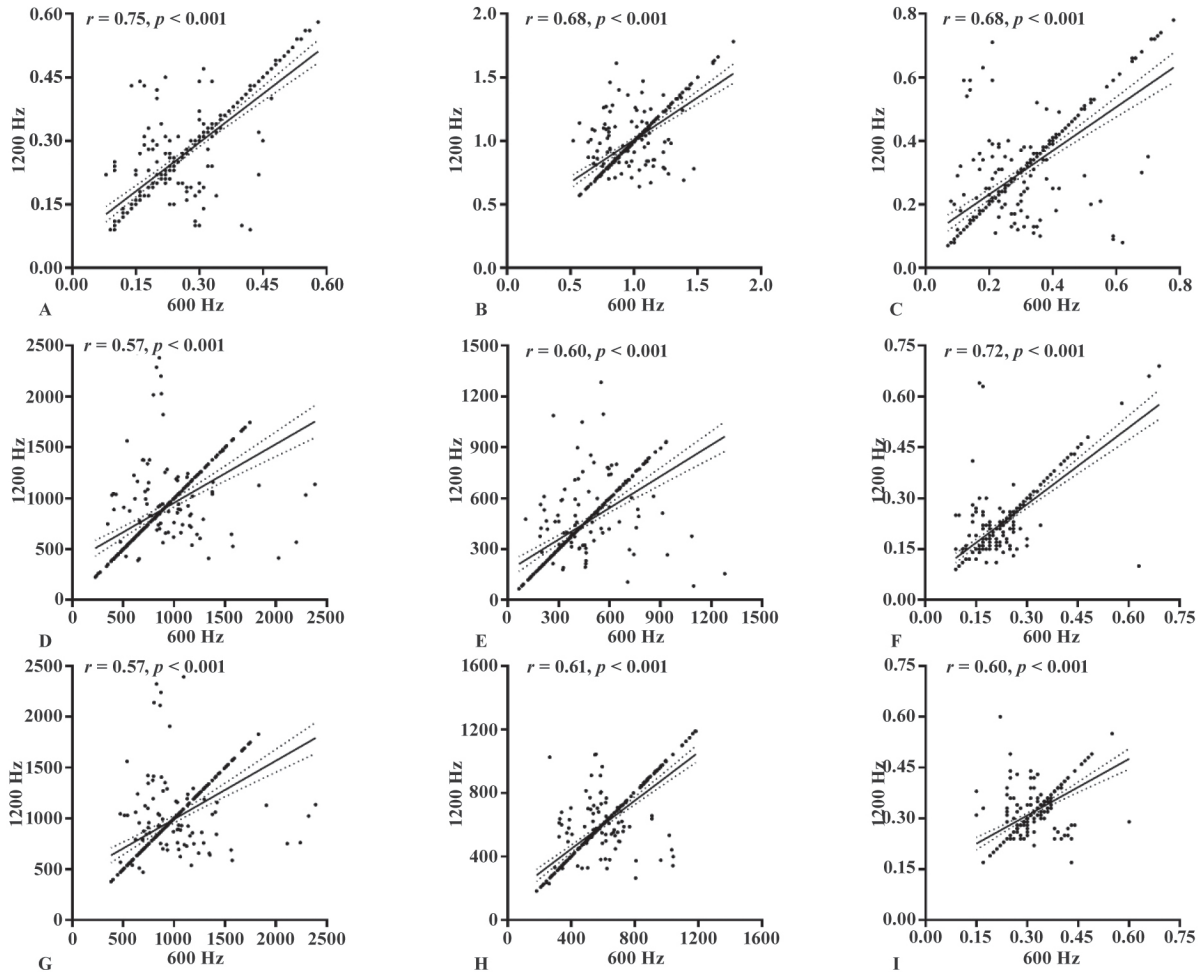


Figure 2. Relationships between 600 and 1200 Hz. A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration

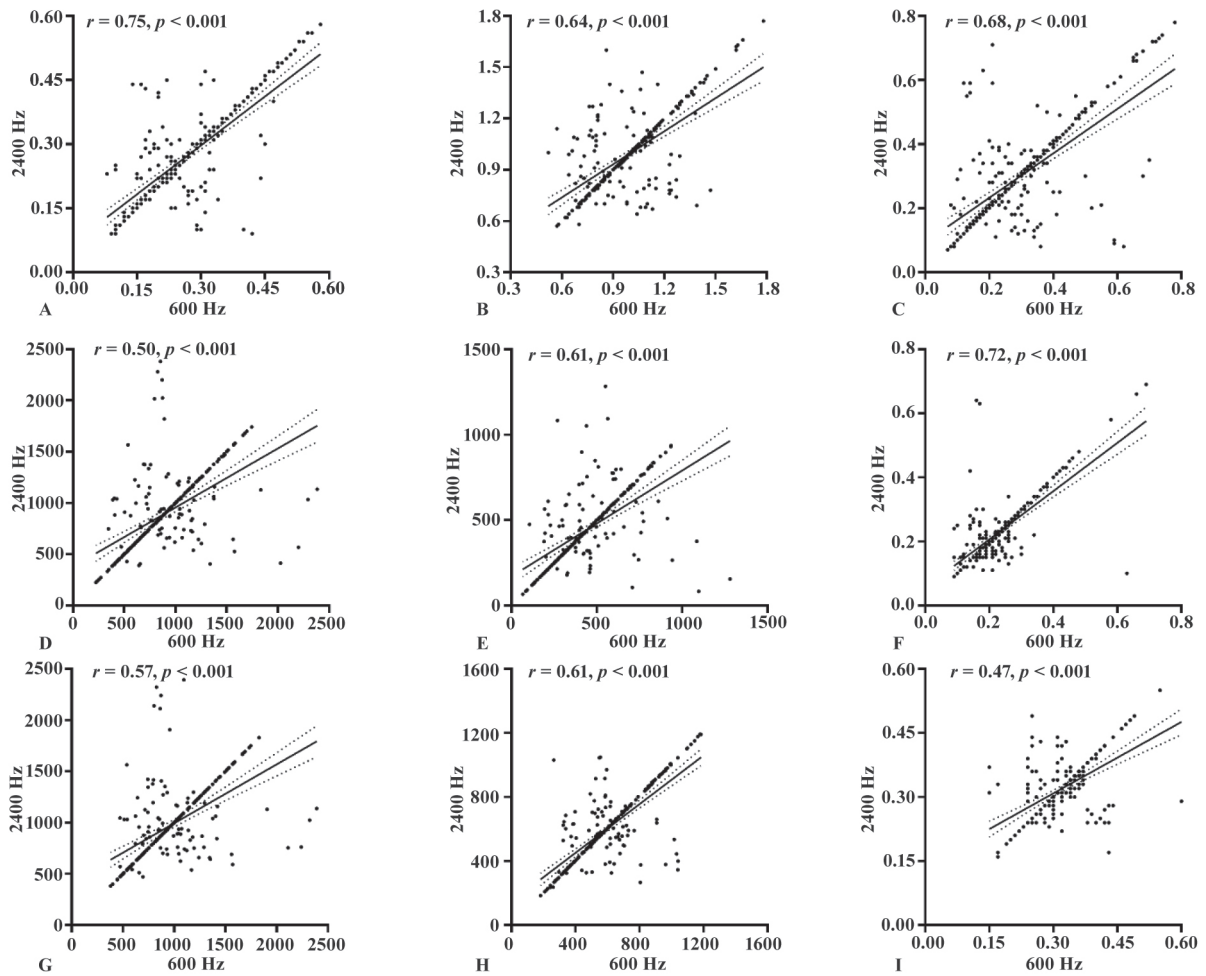


Figure 3. Relationships between 600 and 2400 Hz. A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration

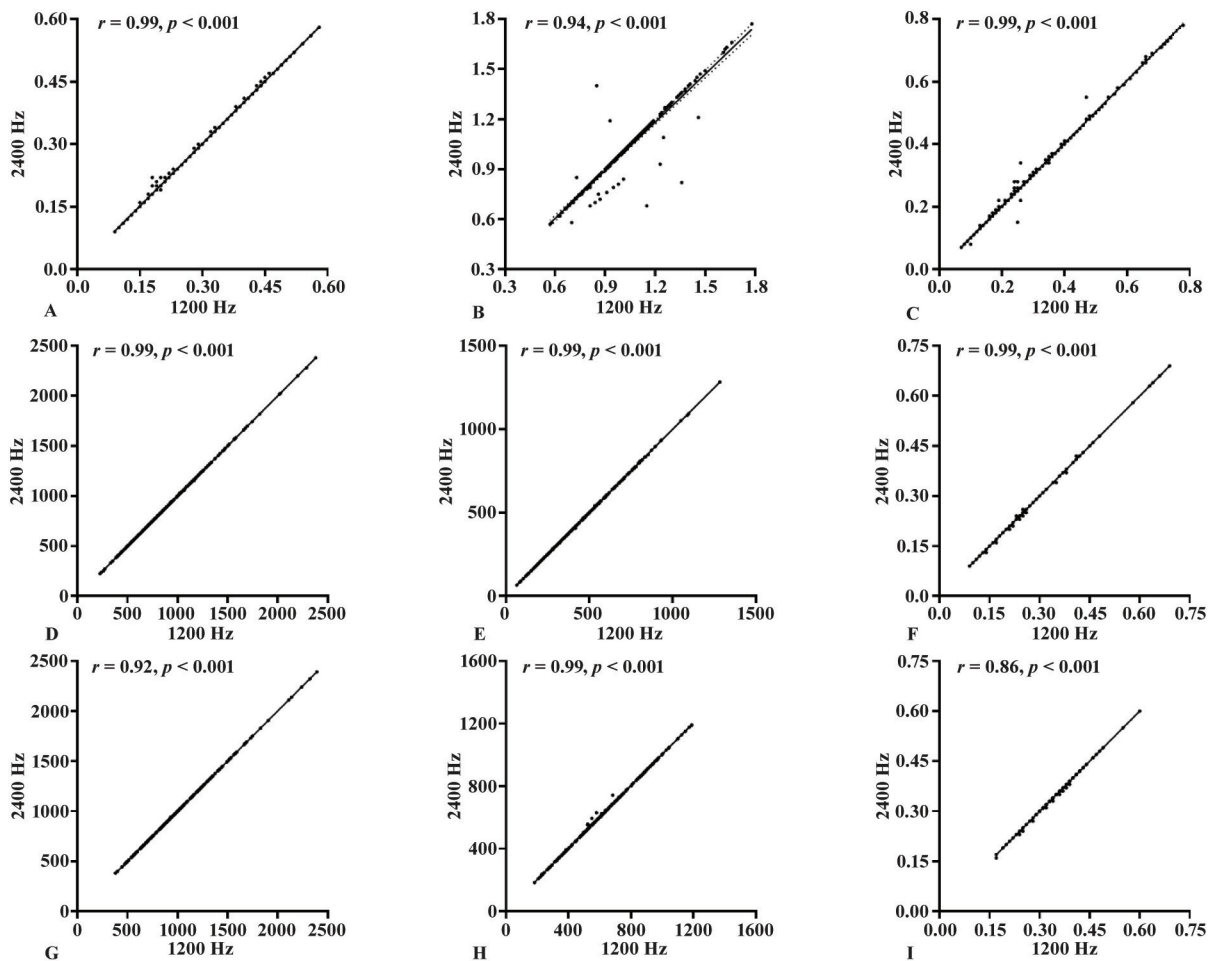


Figure 4. Relationships between 1200 and 2400 Hz. A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration

When examining the agreement between sampling at 600 Hz and 1200 Hz, the strongest level of agreement was in RSImod (mean bias = -0.0005, 95% CI -0.24 – 0.24), and the poorest in peak braking force (mean bias = -0.93, 95% CI -825.6 – 638.1). In the 600 Hz vs 2400 Hz comparison, the strongest agreement was observed for propulsive duration (mean bias = 0.001, 95% CI -0.14 – 0.14),

with the poorest agreement for mean propulsive force (mean bias = -7.34, 95% CI -416.0 – 401.6). Lastly, when comparing the 1200 Hz and 2400 Hz sampling rates, the greatest agreement was observed in jump height (mean bias = -0.001, 95% CI -0.007 – 0.009), and the poorest agreement was observed in peak braking force (mean bias = -89.10, 95% CI -385.3 – 207.1).

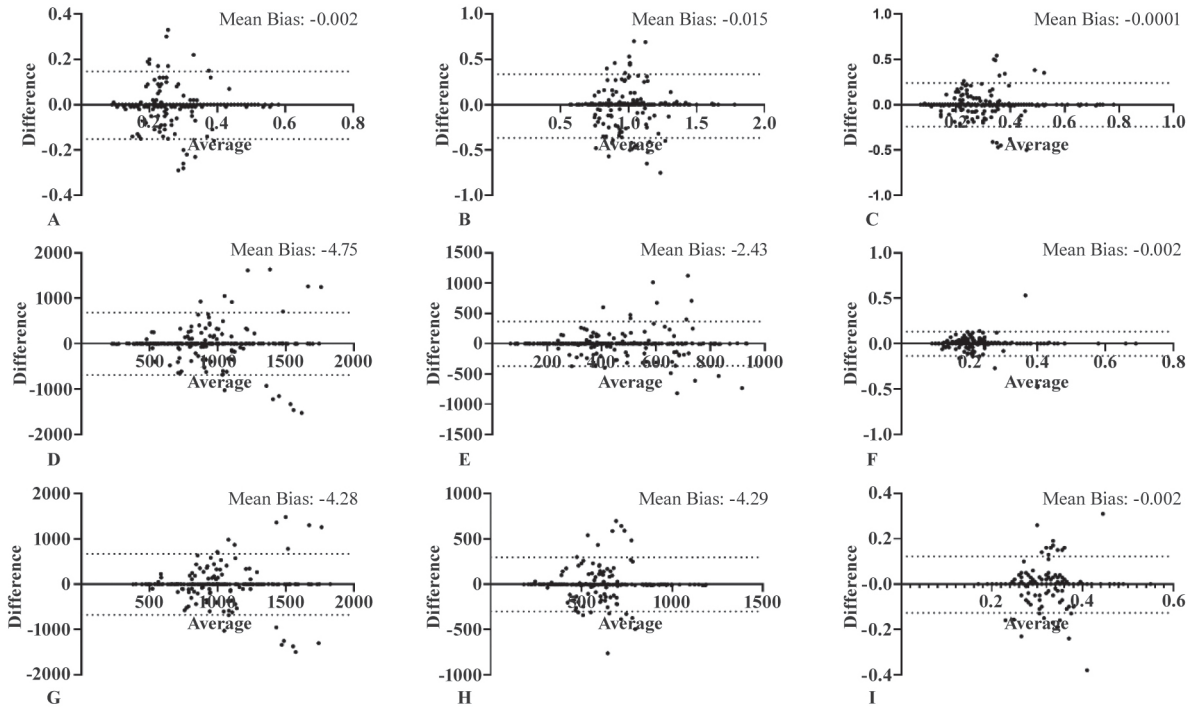


Figure 5. Bland-Altman Comparisons between 600 and 1200 Hz. *A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration*

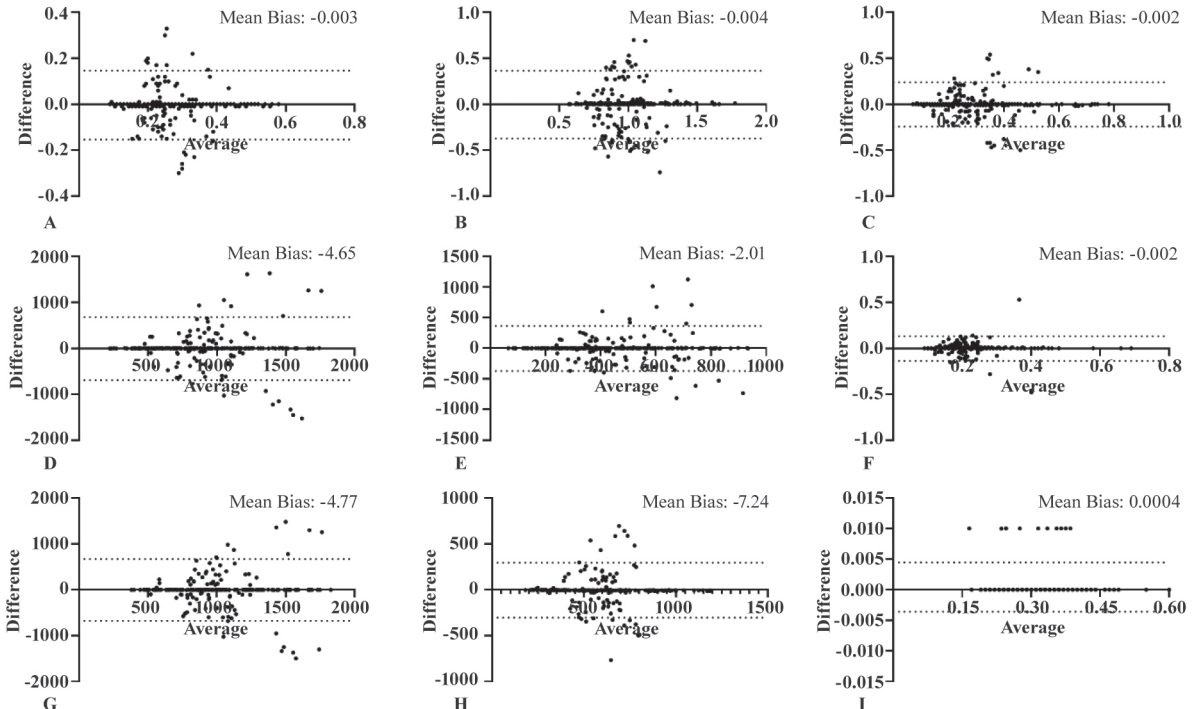


Figure 6. Bland-Altman Comparisons between 600 and 2400 Hz. *A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration*

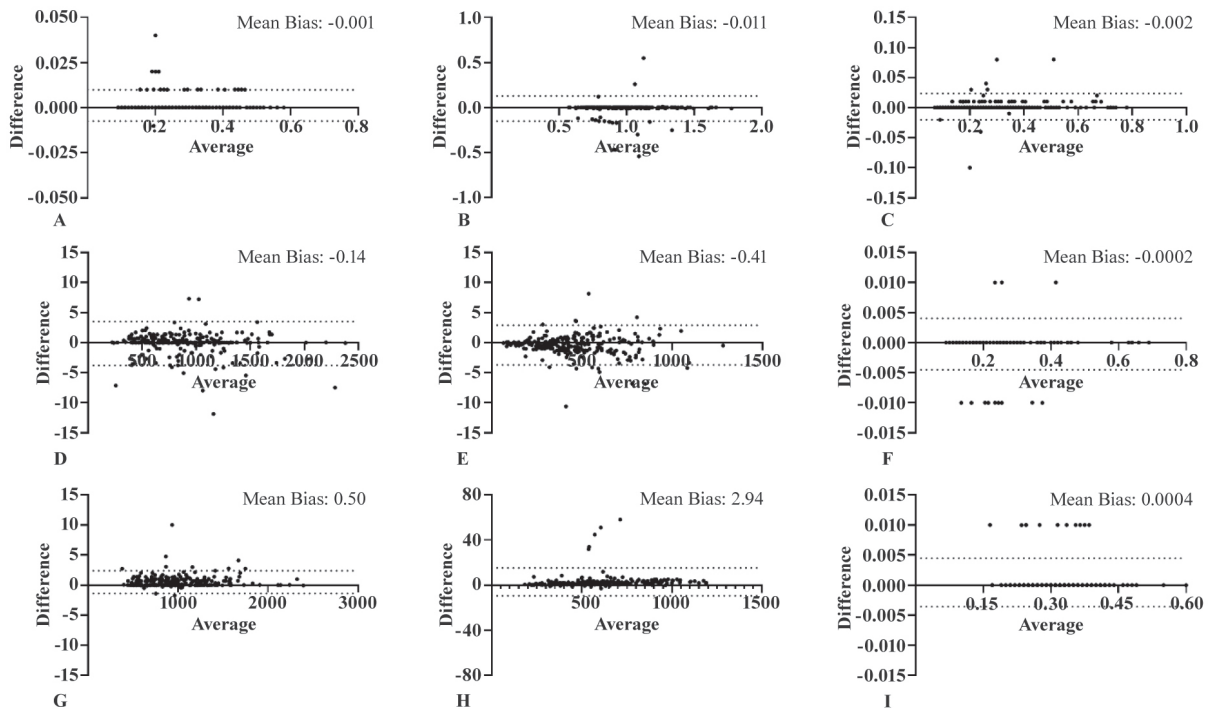


Figure 7. Bland-Altman Comparisons between 1200 and 2400 Hz. A = jump height; B = Time to Takeoff; C = RSImod; D = Peak Braking Force; E = Mean Braking Force; F = Braking Duration; G = Peak Propulsive Force; H = Mean Propulsive Force; I = Propulsive Duration

DISCUSSION

The primary finding of this investigation was that using different sampling frequencies produced no statistically significant results at the group level. Additionally, data from all three frequencies showed moderate-to-near-perfect correlation coefficients. However, based on the figures presented, data interpretation should be approached with caution when comparing frequencies. Examination of the data in Figure 1 shows that the range of each variable is very similar across the three sampling frequencies. However, individual trials can yield markedly different outcomes depending on the sampling frequency used. For jump height, differences in outcomes are bidirectional when comparing 600 Hz with 1200 and 2400 Hz. Consequently, group-level analysis using repeated-measures ANOVA did not detect visually apparent differences between trials.

While this study is not the first to examine

the influence of sampling frequency on CMJ performance, the methodologies used provided a robust understanding of how sampling frequency can affect the interpretation of CMJ data (Hori et al., 2009). Hori et al. reported the reliability of different CMJ metrics across a range of low sampling frequencies (25–500 Hz) using correlation coefficients and percentage change. While reliability measures are critical when examining different sampling frequencies, the differences in the actual data obtained remain critical for understanding how data can be compared across investigations. Hori et al. used 24 participants, making it challenging to detect trivial differences in sampling frequency. In the present study, each trial was treated as a single observation, providing sufficient statistical power for correlational analyses and enabling the detection of subtle differences in sampling frequency. Small, at times, trivial differences may be meaningful at the individual level when mak-

ing decisions about training or performance evaluations for talent identification. Although no variables reached statistical significance and all effect sizes were trivial, bidirectional changes (Figure 1), differences in correlation coefficients, and variations in agreement suggest that each sampling frequency yields slightly different results. Therefore, it is important to consider the totality of the findings rather than relying on a single analysis. All correlations in this study were statistically significant, but the magnitude of the relationships was greater between 1200 Hz and 2400 Hz. The weaker relationships at 600 Hz can partly be explained by the observed bidirectional changes. Inconsistent changes may arise from multiple factors. First, the braking and propulsive phases are defined in terms of the center-of-mass velocity, which is calculated as the integral of the acceleration. Minor timing differences can result in bidirectional variations in phase duration and peak force. Second, errors in takeoff identification can cause variation. Late takeoff identification results in a larger negative impulse just prior to takeoff. This negative impulse can lead to lower jump height values being calculated based on the impulse-momentum relationship and the use of takeoff velocity to calculate jump height. Previous studies have estimated that incorrect takeoff identification can produce jump height errors of 0.3–2.0% (Hatze, 1998; Kibele, 1998; Street et al., 2001). The current study demonstrates that reducing the sampling frequency from 2400 Hz to 1200 Hz did not affect phase or takeoff identification, whereas reducing it to 600 Hz did. Suggesting that comparisons of data obtained at frequencies above 1200 Hz can be made with greater confidence.

Sampling frequencies ranging from 500 to 2400 Hz are commonly reported, which complicates between-study comparisons due

to this methodological factor (Fain et al., 2021; Floría & Harrison, 2013). Previous recommendations state that vertical ground reaction force data should be collected at a minimum of 200 Hz and have continued to be suggested (Chavda et al., 2018; Renner et al., 2022). However, their analyses were limited to 500 Hz, which is the lower end of sampling frequencies reported in the current literature (Lees & Lake, 2007; McMaster et al., 2014; Merrigan et al., 2024; Street et al., 2001). The present study examined a wider range, including 2400 Hz (laboratory-grade), 1200 Hz (portable platform), and 600 Hz (the lower end of the recommended range). Based on these results, we recommend avoiding sampling rates below 1000 Hz whenever possible, as individual-trial data appear to be affected.

As CMJ assessments gain popularity for monitoring neuromuscular status, individual analysis has also become more common (Donahue et al., 2022; Ghigiarelli et al., 2025; Harry et al., 2024). One such technique is to use the CV for each individual. Greater between-trial variability at 600 Hz in this study could substantially affect the ability to detect meaningful change using CV. For example, participant 17 had a mean jump height of 0.24 m (SD 0.03 m) at 600 Hz, compared to 0.30 m (SD 0.004 m) at both 1200 and 2400 Hz. The CV for 600 Hz was 10.79%, versus 1.55% for the other two frequencies. The higher CV values highlight the difficulty of detecting meaningful changes at lower sampling frequencies. Therefore, sampling frequency is a critical methodological consideration for both researchers comparing studies and practitioners using data to inform individualized training decisions.

This study is not without limitations. The sample included recreationally active individuals with a wide range of jump abilities

(0.09–0.58 m), which may reflect the individual differences in the biomechanics and motor coordination and can introduce variability in trial consistency. To mitigate this, each trial was analyzed as an independent observation. Future studies with more homogeneous, experienced jumpers (e.g., athletes in basketball or volleyball) are warranted. Additionally, participants used a dowel to restrict arm swing. Although submaximal practice trials were provided, participants may not have had sufficient time to fully adapt their technical ability to perform a high-level CMJ, particularly with the restricted arm swing. Future studies should consider longer familiarization periods and examine alternative arm-restriction methods, such as hands-on-hips or allowing arm swing. Lastly, only three sampling frequencies were used in the analysis. Although selecting every second and fourth data point allowed examination of a spectrum of frequencies, additional research is needed to determine the lowest acceptable sampling frequency for CMJ and other jump tasks, including squat and rebound jumps.

CONCLUSION

The findings of this study indicate that 1200 Hz and 2400 Hz sampling frequencies demonstrate strong agreement and near-perfect relationships, supporting their comparability across studies and measurement systems. Although trivial differences may occur at the individual-trial level, particularly for force-related variables, these differences did not meaningfully influence group-level outcomes and were substantially smaller between 1200 Hz and 2400 Hz than when 600 Hz was used. Given the widespread use of both laboratory-grade force plates and portable systems sampling at 1200 Hz, the present results suggest that data collected at or above 1200 Hz can be interpreted and compared

with greater confidence across investigations. This has important implications for both comparing results in the CMJ literature and for practitioners seeking to contextualize athlete data relative to published norms, as methodological consistency in sampling frequency remains a critical factor for meaningful between-study comparison.

Statements and Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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