Effect of Sampling Frequency on Isometric Midthigh-Pull Kinetics

Thomas Dos'Santos, Paul A. Jones, Jonathan Kelly, John J. McMahon, Paul Comfort, and Christopher Thomas

Purpose: Skeletal-muscle function can be evaluated using force-times curves generated via the isometric midthigh pull (IMTP). Various sampling frequencies (500–1000 Hz) have been used for IMTP assessments; however, no research has investigated the influence of sampling frequency on IMTP kinetics. Therefore, the purpose of this study was to investigate the influence of sampling frequency on kinetic variables during the IMTP, including peak force, time-specific force values (100, 150, and 200 ms), and rate of force development (RFD) at 3 time bands (0–100, 0–150, 0–200 ms). Methods: Academy rugby league players (n = 30, age 17.5 ± 1.1 y, height 1.80 ± 0.06 m, mass 85.4 ± 10.3 kg) performed 3 IMTP trials on a force platform sampling at 2000 Hz, which was subsequently down-sampled to 1500, 1000, and 500 Hz for analysis. Results: Intraclass correlation coefficients (ICC) and coefficients of variation (CV) demonstrated high within-session reliability for all force and RFD variables across all sampling frequencies (ICC ≥ .80, CV ≤ 14.4%) except RFD 0–100 and 0–150, which demonstrated slightly greater levels of variance (CV = 18.0–24.1%). Repeated-measures analysis of variance revealed no significant differences ($P > .05$, Cohen $d \leq 0.0171$) in kinetic variables between sampling frequencies. Overall, high reliability was observed across all sampling frequencies for peak force, time-specific force, and RFD 0- to 200-ms variables, with no significant differences ($P > .05$) for each kinetic variable across sampling frequencies. Conclusions: Practitioners and scientists may consider sampling as low as 500 Hz when measuring peak force, time-specific force values, and RFD at predetermined time bands during the IMTP for accurate and reliable data.

Keywords: peak force, rate of force development, reliability, force-time curve

Skeletal-muscle function can be evaluated using force-time curves generated during dynamic and isometric activities. Peak force (PF) and peak rate of force development (RFD) are commonly assessed[1–5] and have been reported to relate to various athletic performance tasks including baseball batting,[6] change-of-direction speed,[7] weightlifting,[5,8,9] cycling,[10] jumping,[11,12] and throwing.[13] The advantages of the isometric midthigh pull (IMTP) are that it is relatively easy to perform while demonstrating high reliability[2,3,14] with a low measurement error.[15,16] The test only requires a single maximum contraction inducing minimal fatigue[14,17]; it is a time efficient method compared with dynamic 1-repetition-maximum testing,[5] and it provides insight into the athlete's capabilities to produce PF, RFD, impulse, and force at specific time points.[2,16,18] Note that the IMTP can be used to monitor the effectiveness of training interventions and fatigue, to assess neuromuscular prepared-ness for weightlifting competition, and for talent identification.[8] Furthermore, recent research has used the IMTP to investigate dynamic-strength indexes of college athletes.[19]

Variations in IMTP kinetics reported across the literature may be partially explained by methodological differences.[2,8,13 ,16,18] Early research used a sampling frequency of 500 Hz and 600 Hz,[8,13] whereas more recent investigations have implemented [illegible] influence kinetic output. Methods used to calculate variables from the force-time curve, in particular the method of calculating RFD, may also vary across the literature.[2] Methods previously used include preset time intervals,[2,5] using the slope of the force-time curve (A force/A time) from initial rise to maximum force produced (mean RFD),[22] and different sampling windows (2–50 millise-conds) to determine peak rfd.[4,5,8 ,20,21] Haff et al[2] proposed that the chosen method to quantify RFD could influence the interpretation of results, therefore potentially impeding scientists' and practi-tioners' diagnosis of performance characteristics. The sampling window used to quantify RFD can affect the result and reliability of the RFD measure; thus, a sampling window of 20 milliseconds is recommended when calculating peak RFD.[2] Conversely, using predetermined time bands for the calculation of RFD offers greater reliability than peak RFD (sampling windows) and therefore is recommended for the calculation of RFD.[2] It is worth noting that the slope of the force-time curve (A force/A time) and changes over specified epochs result in mean RFD, albeit for a given time frame.

There is agreement across the literature that the IMTP is highly reliable for obtaining PF measurements for athletes across a range of sampling frequencies (500–1000 Hz), with intraclass correlations coefficients (ICC) reported of ≥.98 when sampled at 500 Hz,[13] 600 Hz,[1,3,8,10] and 1000 Hz.[2,4] Conversely, reliability for RFD is lower, with ICCs reported of .80 to .81 when sampled at 500 Hz,[13] 600 Hz,[3,8,10] and 1000 Hz.[4] This could be explained by the varied methods of calculating RFD. For example, Haff et al[2] demonstrated that mean RFD failed to meet reliability standards (>15% CV threshold) and illustrates predetermined time bands to observe higher reliability measures for calculating RFD (ICC > .95, CV <4%).

Sampling frequency may also affect the resultant outputs from the IMTP.[23,24] McMaster et al [23] recommend a sampling frequency of 500 to 2500 Hz for the IMTP assessment, and a sampling frequency of 1000 to 2500 Hz is recommended for measuring RFD.[23] Nyquist's sampling theorem[25] states that to ensure that none of the original signal is lost during the sampling process and to prevent aliasing, a sampling frequency of double the highest frequency contained in the signal is necessary. Sampling at fre-quencies below the critical frequency may lose vital pieces of the original signal (ie, peak values).[23] Therefore, previous research that sampled below the recommended 1000 to 2500 Hz may not have ing the lower ICC reported for RFD than with PF across the literature.

No research has investigated the influence of sampling fre-quency on IMTP kinetics. Previously, Hori et al[26] investigated the influence of sampling frequency on countermovement-jump (CMJ) ground-reaction-force variables, while Owen et al[24] investigated the influence of sampling frequency on[2,8,10] peak mechanical power output during the CMJ. No research has investigated sampling frequencies greater than 1000 Hz when implementing the IMTP, where a higher sampling frequency may result in greater accuracy and a [2,4] higher peak value may be obtained.[24] Strength and condi-tioning practitioners require information regarding the effect of sampling frequency on the reliability and accuracy of IMTP kinetics so they can make informed decisions balancing accuracy and reliability with reductions in data-file sizes.[26]

The purpose of this study, therefore, was to investigate the influence of sampling frequency (500, 1000, 1500, and 2000 Hz) on the reliability of IMTP kinetics including PF, time-specific force values (100, 150, and 200 milliseconds), and RFD at predetermined time bands (0–100, 0–150, and 0–200 milliseconds) and to deter-mine if any there were any differences in each variable between sampling frequencies. This research should provide practitioners with recommendations regarding sampling frequency for the IMTP test to obtain reliable and comparable measurements of kinetic variables. We hypothesized that higher reliability measures for kinetic variables would be obtained with higher sampling frequen-cies. We also hypothesized that higher sampling frequencies would result in higher peak values for all variables.

Methods

Subjects

Professional academy rugby league players (N = 30, age 17.5 ± 1.1 y, height 1.80 ± 0.06 m, mass 85.4 ± 10.3 kg) provided informed consent to participate in this study, which was approved by the university ethics committee. Subjects were familiar with the IMTP and were experienced with weightlifting movements (≥2 y weight-training experience); all IMTP trials were assessed by qualified strength and conditioning coaches. At the time of testing subjects were in the second week of their preseason mesocycle.

Design

A repeated-measures, within-subjects design was used to deter-mine the effects of sampling frequency on PF, time-specific force values (100, 150, and 200 milliseconds), and RFD at predetermined time bands (0–100, 0–150, and 0–200 milliseconds). Subjects performed 3 maximal IMTPs while standing on a force plate sampling at 2000 Hz, which was subsequently down-sampled to 1500, 1000, and 500 Hz to permit calculation of kinetic variables at different sampling frequencies. Reliability was assessed across trials, and the peak value of the 3 trials was compared for all kinetic variables across sampling frequencies to explore any differences in values.

Procedures

Pre-Isometric-Assessment Warm-Up. All subjects performed a standardized warm-up comprising 5 minutes of dynamic stretching before advancing to dynamic midthigh clean pulls. One set of 5 repetitions was performed with an empty barbell (Werksan Olympic Bar, Werksan, Moorsetown, NJ, USA) followed by 3 isometric efforts at perceived intensities of 50%, 70%, and 90% of maximum effort, interspersed with 1-minute recoveries.

Isometric Midthigh-Pull Protocol. The IMTP testing was con-ducted with subjects standing on a portable force platform (Kistler, Switzerland, Model 9286AA, SN 1209740) positioned on the center of the floor within a power rack. An immovable weightlifting bar (Werksan Olympic Bar, Werksan, Moorsetown, NJ, USA) was clamped down to the crash bars of the power rack with ratchet straps, similar to methods employed by Khamoui et al.[22] The bar was positioned to correspond to each athlete's second- pull power-clean position[2] just below the crease of the hip; the bar height could be adjusted at various heights above the force plate to accommodate different-size athletes, and the power rack was anchored to the floor.

Athletes were strapped to the bar in accordance with previous research[8,10] and positioned in their self-selected midthigh-clean position established in the familiarization trials, whereby feet were shoulder width apart, knees were flexed over the toes, shoulders were just behind the bar, and torso was upright. Research has demonstrated that differences in knee and joint angles during the IMTP do not influence kinetic variables,[16] justifying the self-selected preferred midthigh position. All subjects received stan-dardized instructions to pull as fast and as hard as possible until being told to stop, as these instructions have been shown to be optimal in producing maximum PF and RFD results.[4,20] The IMTP was initiated with the countdown "3, 2, 1 pull," with subjects ensuring that maximal effort was applied for 5 seconds based on previous protocols.[2,8] Verbal encouragement was given for all trials and subjects. Subjects performed a total of 3 maximal-effort trials lasting 5 seconds and interspersed with 1-minute recoveries.[7,11]

All ground-reaction-force data were sampled at 2000 Hz for a duration of 8 seconds via a portable force platform (Kistler, Switzerland, Model 9286AA, SN 1209740) interfaced with a laptop. Data were later analyzed using Bioware software (Version 5.11, Kistler Instrument Corp, Switzerland) and down-sampled to 1500, 1000, and 500 Hz for subsequent analysis. The onset of the pull was determined when vertical ground-reaction force exceeded the onset threshold of 75 N.

Isometric Force-Time-Curve Assessment. All force-time-curve data generated during the IMTP were inspected using a customized analysis spreadsheet to determine specific force-time characteris-tics, with data smoothed using a moving-average window of 20 milliseconds. The maximum force generated during the 5-second maximum- effort IMTP was reported as the absolute PF.[2] In addition, time-specific force values (100, 150, and 200 milli-seconds) and RFD at predetermined time bands (0–100, 0–150, and 0–200 milliseconds) from the onset of the pull (duration after onset threshold exceeded 75 N) were determined for each trial. This was in accordance with previous studies that used similar predeter-mined time bands when calculating force and RFD and demon-strating high reliability.[2,5,12,18] Specifically, RFD was calculated using the equation RFD = A force/A time interval. This equation was applied to the time bands 0 to 100, 0 to 150, and 0 to 200 milliseconds.[2,5] These time intervals were selected based on typical ground-contact times experienced during various athletic movements, for example, sprinting, jumping, and changingdirection.[27–29] For this reason time bands <100 milliseconds were not selected.

sampling frequencies 500, 1000, 1500, and 2000 Hz. Statistical significance was defined as $P \leq .05$ for all tests.

Statistical Analyses

Normality was inspected using a Shapiro Wilk test using SPSS software version 20 (SPSS, Chicago, IL, USA). Reliability was assessed via ICC, 95% confidence intervals (CI), and coefficient of variation (CV) between the 3 trials to assess within-session reli-ability for each kinetic variable across all sampling frequencies with the use of a custom spreadsheet.[30]

The CV was calculated based on the mean-square-error term of logarithmically transformed data.[30] Haff et al[2] argue that although ICCs are common to report the reliability, CIs should be reported, as "a more informative depiction of the reliability measure can be made."(p392) Minimum acceptable reliability was determined with an ICC $>$ .7 and CV $<$15%.[2,31,32] The magnitude of differences for kinetic variables between sampling frequencies were calculated by the formula of Cohen $d = M - M2/a$ pooled, where a pooled $=$ the square root of ($a1^2 + a2^2/2$).[33] Cohen d effect sizes were character-ized as trivial ($<$0.19), small (0.20-0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (2.0–4.0).[34] Power was calculated using G*Power (Version 3.1, University of Düsseldorf, Germany).[35]

Repeated-measures analysis of variance (RMANOVA) was conducted via SPSS to determine if there were significant differ-ences in the maximum values of PF, time-specific force values (100, 150, and 200 milliseconds), and RFD at predetermined time bands of 0 to 100, 0 to 150, and 0 to 200 milliseconds between

Results

The Shapiro Wilk test of normality revealed that all data were normally distributed ($P > .05$). ICC and CV demonstrated high within-session reliability for all force and RFD variables except RFD 0 to 100 and 0 to 150 milliseconds across all sampling frequencies (ICC ≥ .80, CV ≤ 14.4%) (Table 1), achieving ICC and CV minimum-acceptable-reliability criteria. Descriptive statistics for all force and RFD variables at each sampling frequency are presented with statistical power in Tables 2 and 3. Specifically, absolute PF demonstrated the highest overall reliability across all sampling frequencies (ICC = .97, CV = 3.2%). RFD 0 to 200 milliseconds demonstrated the greatest overall reliability in comparison with the other RFD variables across all sampling frequencies (ICC = .93, CV = 14.2–14.4%). Overall, there was little difference in ICC and CV across sampling frequencies for each respective force and RFD variable (Table 1).

RMANOVA revealed there were no significant differences ($P > .05$, Cohen $d \le 0.009$) in force variables between sampling frequencies. Pairwise comparisons showed trivial and nonsignifi-cant differences between 2000 Hz and 1500 Hz ($P = 1.00$, Cohen $d = 0.0007$), 2000 Hz and 1000 Hz ($P = 1.00$, Cohen $d = 0.0006$), 2000 Hz and 500 Hz ($P = 1.00$, Cohen $d = 0.0022$), 1500 Hz and 1000 Hz ($P = .49$, Cohen $d = 0.0006$), 1500 Hz and 500 Hz ($P = 1.00$, Cohen $d = 0.0030$), and 1000 Hz and 500 Hz ($P = 1.00$, Cohen $d = 0.0048$) for PF.

Table 1 Within-Session Reliability Measures (95% CI) Between 3 Trials for Kinetic Variables During the Isometric Midthigh Pull Across Sampling Frequencies

	2000 Hz		1500 Hz		1000 Hz		500 Hz	
Kinetic variable	ICC	CV%	ICC	CV%	ICC	CV%	ICC	CV%
Absolute PF, N	.97 (.94–.98)	3.2 (2.7–4.1)	.97 (.94–.98)	3.2 (2.7–4.1)	.97 (.94–.98)	3.2 (2.7–4.1)	.97 (.94–.98)	3.2 (2.7–4.1)
Force at 100 ms, N	.80 (.66–.90)	10.1 (8.4–13.0)	.81 (.68–.90)	9.6 (8.0–12.3	.81 (.68–.90)	9.6 (8.0–12.3	81 (.67–.90)	10.1 (8.4–13)
Force at 150 ms, N	.85 (.74–.92)	8.7 (7.2–11.1)	.86 (.75–.93)	8.5 (7.0–10.8)	.86 (.75–.93)	8.6 (7.1–11.0)	.86 (.75–.92)	8.6 (7.1–11.0)
Force at 200 ms, N	.90 (.82–.95)	7.7 (6.3–9.8)	.90 (.82–.95)	7.5 (6.2–9.5)	.90 (.83–.95)	7.3 (6.1–9.4)	.90 (.82–.95)	7.7 (6.3–9.8)
RFD 0–100 ms, N/s	.81 (.65–.90)	24.1 (19.1–29.1)	.81 (.65–.90)	23.4 (18.7–28.1)	.81 (.66–.91)	23.6 (18.9–28.3)	.81 (.66–.90)	23.9 (18.9–28.9)
RFD 0–150 ms, N/s	.89 (.80–.94)	18.0 (14.2–21.8)	.89 (.79–.94)	18.5 (14.4–22.2)	.89 (.80–.94)	18.2 (14.5–21.9)	.89 (.80–.94)	18.3 (14.5–22.2)
RFD 0–200 ms, N/s	.93 (.87–.96)	14.2 (10.3–18.1)	.93 (.87–.96)	14.4 (10.7–18.2)	.93 (.88–.97)	14.4 (10.6–18.1)	.93 (.87–.96)	14.4 (10.5–18.3)

Abbreviations: ICC, intraclass correlation coefficient; CV, coefficient of variation; RFD, rate of force development; PF, peak force.

Table 2 Raw Force Values During the Isometric Midthigh Pull Across Sampling Frequencies, Mean ± SD

Kinetic variable	2000 Hz	1500 Hz	1000 Hz	500 Hz	Statistical power
Absolute peak force (N)	2790 ± 457	2790 ± 456	2790 ± 456	2789 ± 457	.99
Force at 100 ms (N)	1632 ± 334	1630 ± 333	1629 ± 333	1629 ± 331	.78
Force at 150 ms (N)	1973 ± 428	1973 ± 428	1973 ± 428	1972 ± 428	.89
Force at 200 ms (N)	2189 ± 414	2189 ± 414	2188 ± 414	2186 ± 414	.91

Table 3 Raw Rate of Force Development (RFD) at Predetermined Time Bands During the Isometric Midthigh Pull Across Sampling Frequencies, Mean ± SD

Kinetic variable	2000 Hz	1500 Hz	1000 Hz	500 Hz	Statistical power
RFD 0–100 ms (N/s)	5311 ± 1916	5333 ± 1881	5322 ± 1906	5300 ± 1927	.77
RFD 0–150 ms (N/s)	5624 ± 1944	5632 ± 1910	5628 ± 1936	5628 ± 1937	.85
RFD 0–200 ms (N/s)	5403 ± 1727	5399 ± 1725	5407 ± 1728	5393 ± 1728	.87

Pairwise comparisons showed trivial and nonsignificant differ-ences between 2000 Hz and 1500 Hz ($P > .05$, Cohen $d \le 0.0060$), 2000 Hz and 1000 Hz ($P > .05$, Cohen $d \le 0.0090$), 2000 Hz and 500 Hz ($P > .05$, Cohen $d \le 0.0090$), 1500 Hz and 1000 Hz ($P > .05$, Cohen $d \le 0.0030$), 1500 Hz and 500 Hz ($P > .05$, Cohen $d \le 0.0060$), and 1000 Hz and 500 Hz ($P > .05$, Cohen $d \le 0.0060$) for time-specific force values (100, 150, and 200 milliseconds).

RMANOVA revealed no significant differences ($P > .05$, Cohen $d \le 0.0171$) in RFD variables between sampling frequen-cies. Pairwise comparisons showed trivial and nonsignificant differences ($P = 1.00$, Cohen $d \le 0.0171$) between all sampling frequencies for RFD variables.

Discussion

The aims of this study were to investigate the influence of sampling frequency on IMTP kinetics and to determine its effect on the within-session reliability and resultant outputs between sampling frequencies. The results from this study demonstrated high within-session reliability for all kinetic variables (except RFD 0–100 and 0–150 milliseconds) across all sampling frequencies (ICC ≥ .80, CV ≤ 14.4%), achieving minimum-acceptable-reliability criteria, with little difference in ICC and CV between sampling frequencies for each respective kinetic variable (Table 1). Furthermore, no significant differences ($P > .05$, Cohen $d \le 0.0171$) were observed across all force and RFD variables between sampling frequencies. Therefore, it appears the sampling frequency has little effect on the within-session reliability and accuracy of the resultant outputs during the IMTP. This suggests that sampling at frequencies as low as 500 Hz for the IMTP is sufficient to obtain highly reliable and accurate measurements of absolute PF, time-specific force values, and RFD at predetermined time bands, in contrast to the hypotheses.

McMaster et al[23] recommend a sampling frequency of 500 to 2500 Hz when performing the IMTP assessment; specifically for the calculation of RFD, a sampling frequency of 1000 to 2500 Hz was further recommended. However, the current study is the first to investigate the influence of sampling frequency on IMTP kinetics, in line with the recommendation of McMaster et al.[23] Note that high within-session reliability for all kinetic variables was found when sampled at 500 Hz (Table 1); specifically, RFD at predetermined time bands demonstrated high ICCs (.81–.93) when down-sampled to 500 Hz, similar to ICC measures reported in other investigations that sampled at 1000 Hz[2,5] and comparable to the values when sampling at 2000 Hz. However, it should be noted that RFD 0 to 100 and 0 to 150 milliseconds demonstrated greater levels of variance and exceeded the unacceptable CV threshold, in contrast to RFD 0 to 200 milliseconds, which met the acceptable CV criteria. Therefore, the results from this study suggest that sampling at 500 Hz is reliable for calculating RFD at predetermined time bands, lower than the 1000- to 2500-Hz suggestions from McMaster et al.[23]

Similar research has investigated the influence of sampling frequency during the CMJ.[24,26] Hori et al[26] investigated thereliability of performance measurements from ground-reaction-force data during the CMJ and the influence of sampling frequency (500, 400, 250, 300, 100, 50, and 25 Hz). Peak power, PF, and peak velocity demonstrated high reliability across sampling frequencies (ICC = .92–98, CV = 1.3–4.1%), but peak RFD did not (ICC ≤ .75, CV ≥ 20.7%). Similarly, time to peak power demonstrated high reliability at sampling frequencies of 50 to 500 Hz (ICC = .83–.85, CV = 6.8–7.5%), but low reliability was observed at 25 Hz (ICC = .57, CV = 14.4%). The authors recommended sampling as low as 200 Hz for the CMJ but not at frequencies of ≤100 Hz. Similarly, Owen et al[24] investigated the effect of sampling frequency on peak mechanical power output obtained from the CMJ sampling at 1000, 500, and 100 Hz and reported that sampling frequency had no effect on the determination of body weight; however, they recom-mended sampling at 1000 Hz for the measurement of peak mechanical power output during the CMJ. The sampling frequency of 100 Hz when compared with 1000 Hz produced a mean difference of 87 W and limits of agreement of 144 and 31 W. In addition, a mean difference of 8 W with limits of agreement of 24 and −11 W was reported when a sampling frequency of 500 Hz was compared with 1000 Hz. This is in contrast to findings of this study that showed high reliability for all kinetic variables across sampling frequencies (Table 1), with no significant differences ($P > .05$) in kinetic variables, although this may be due to the ballistic nature of the CMJ in the previous study.

The majority of research using the IMTP has generally sampled at 500 Hz,[13] 600 Hz,[1,3,8,10] or 1000 Hz.[2,4,5,18] The current study is the first to sample at 2000 Hz, which was then down-sampled to 1500, 1000, and 500 Hz to determine the effect on kinetic variables. We hypothesized that a higher sampling frequency would result in higher peak values obtained during the IMTP and higher reliability. In theory, the chosen sampling frequency may affect the resultant output[23]; Nyquist's sampling theorem[25] states that to ensure that none of the original signal is lost during the sampling process and to prevent aliasing, a sampling frequency of double the highest frequency contained in the signal is necessary. Sampling at frequen-cies below the critical frequency may lose vital pieces of the original signal (ie, peak values).[23] Note that sampling frequencies of 2000 Hz and 1500 Hz had little influence on the resultant outputs or reliability measures for all kinetic variables, with no significant differences ($P > .05$) reported across kinetic variables and sampling frequencies. Consequently, it may be unnecessary to sample at frequencies >1000 Hz during the IMTP.

RFD at predetermined time bands (0–100, 0–150, and 0–200 milliseconds) demonstrated high ICCs across all sampling frequencies (ICC = .81–.93), which was in accordance with previ-ous research that demonstrated similar reliability measures.[2,5] However, it should be noted that RFD 0- to 100- and 0- to 150-millisecond variables demonstrated CV values that slightly exceeded the acceptable reliability threshold (Table 1). Specifi-cally, Haff et al[2] reported higher reliability measures for RFD time bands (ICC > .95, CV < 4%) than the current study. Similarly, Beckham et al[5] reported ICC values for RFD time bands between 0 to 100, 0 to 150, 0 to 200, and 0 to 250 milliseconds (ICC = .89, .92, .95, and .95) sampled at 1000 Hz. Therefore, the results from this study confirm that predetermined time bands are highly reliable for calculations of RFD. However, it should be noted that RFD 0- to 100- and 0- to 150-millisecond variables demonstrated CV values that slightly exceeded the acceptable reliability threshold (Table 1).

The ability to generate high force over short time intervals is of great importance for sporting success, whereby it is argued that the ability to apply force quickly is more important than maximum force production for many sports and dynamic tasks.[13, 36–38] Subsequently, the ability to accurately determine the force and RFD-production capabilities of athletes while obtaining valid and reliable measures of time-specific force values and RFD for athletes is key for monitoring athletic performance. In the current study, PF demonstrated the highest reliability across all sampling frequencies (ICC = .97, CV = 3.2%); this is in line with the work of Haff et al,[2] who also found PF to demonstrate the highest reliability (ICC = .99, CV = 1.7%) when sampled at 1000 Hz. Likewise, Comfort et al[16] also found PF to demonstrate the highest within-session reliability (ICC = .993) during the IMTP at preferred hip and knee joint angles. This protocol was also administered in the current study, resulting in comparable reliability measures for PF. Furthermore, similar ICCs have also been reported for PF when sampled at 500 Hz of .98[13] and ≥.98 when sampled at 600 Hz.[1,3,8,10] Therefore, sampling as low as 500 Hz is acceptable for reliable and accurate measures of absolute PF during the IMTP.

Reliability of time-specific force values (100, 150, and 200 milliseconds) reported during the IMTP[2,5,12,18] is also similar to that reported across sampling frequencies (ICC = .80–.90, CV = 7.3–10.1%) in this study. Beckham et al[5] reported similar reliability measures for time-specific force values (100, 150, 200, and 250 milliseconds; ICC = .84, .89, .94, and .94) in a weightlifting population, while Kraska et al[12] reported ICC values for time-specific force values (50, 90, and 250 milliseconds; ICC = .79, .98, and .94); both sampled at 1000 Hz. Furthermore, Haff et al[2] reported higher reliability measures for time-specific force values (30, 50, 90, 100, 150, 200, and 250 milliseconds; ICC = .99, CV = 2.3–2.7%) in female volleyball players sampled at 1000 Hz. Consequently, sampling as low as 500 Hz is acceptable for reliable and accurate measures of time-specific force values during the IMTP.

Practical Applications

Overall, this study confirmed that the IMTP produces high within-session reliability for kinetic variables across sampling frequencies (500–2000 Hz) with no significant differences in the maximum resultant outputs for each kinetic variable between sampling frequencies. Therefore, practitioners and scientists may consider sampling as low as 500 Hz for PF, time-specific force values (100, 150, and 200 milliseconds), and RFD at predetermined time bands (0–200 milliseconds) during the IMTP for accurate and reliable data. Sampling at a lower sampling frequency should allow scientists and practitioners greater access to less expensive portable force platforms; this should enable athletic-performance monitor-ing to be performed confidently at training sites rather than the laboratory. Scientists and practitioners are encouraged to keep the sampling frequency consistent between testing occasions to allow valid comparisons of performance variables when monitoring and tracking athletic performance.

Conclusion

Sampling frequencies as low as 500 Hz for PF, time-specific force values (100, 150, and 200 milliseconds), and RFD at predetermined time bands (0–200 milliseconds) during the IMTP result in accurate and reliable data, with no apparent requirement to sample at higher frequencies.

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