Title:

Within- and between-session reliability of the isometric mid-thigh pull in young female athletes

Running head

Reliability of the IMTP in young females

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ABSTRACT

To investigate the within- and between-session reliability of the isometric mid-thigh pull (IMTP) in pre- and post-peak height velocity (PHV) female athletes. Nineteen pre- and nineteen post-PHV athletes performed bilateral IMTPs using a custom-designed isometric testing system. Participants attended three separate testing-sessions, and performed three trials within each session. Peak force, relative peak force, force at 30, 50, 90, 100, 150, 200, and 250 milliseconds, rate of force development (RFD) within time-specific bands, time to peak force (TPF), and time to peak rate of force development (TPRFD) were obtained for analysis. Within- and between-session reliability for each variable were calculated from repeated-measures analysis of variance, intraclass correlation coefficients (ICC), and coefficients of variation (CV) with 95% confidence intervals. Within- and between-session measures of absolute and relative peak force were found to be reliable for both pre-PHV (CV ≤ 9.4%, ICC ≥ 0.87) and post-PHV (CV ≤ 7.3%, ICC ≥ 0.92), but systematic bias was evident between-sessions in the pre-PHV group, from session 1 to 2. Analyses of force at the specific time-points revealed CVs between 19-37% and 5-24% for pre-PHV and post-PHV athletes respectively. Greater variability was evident in TPF, and all RFD-related variables for pre-PHV (CV = ≥38%) and post-PHV (CV = ≥27%) athletes respectively. The IMTP appears a reliable and safe method for evaluating peak force in young female athletes. Overall, post-PHV athletes were more reliable than pre-PHV athletes, with pre-PHV athletes needing additional familiarization to minimize the influence of systematic bias.

INTRODUCTION

There is now a recognized consensus regarding the importance of prioritizing the training of muscular strength in children and adolescents (19, 21). Support for this approach is based on empirical evidence showing that enhancing muscular strength in young athletes can improve proxies of physical performance (19), reduce sports-related injury risk (29), and positively affect various aspects of health and well-being (21). From a performance perspective, muscular strength underpins the ability to proficiently develop fundamental movement skills, and is critical to the acquisition of all other fitness components (1).

Valid methods of assessing maximal muscular strength include; repetition maximum tests, predictive tests, isometric assessments, and eccentric protocols (25). Using tests that can differentiate between growth-related and training-induced adaptations in strength and power is critical in younger populations, as these fitness qualities are likely to increase due to growth and maturation (2). Current methods of assessing young athletes' maximal force-producing capacities have included 1 repetition maximum (1RM) tests (8). Researchers have demonstrated that 1RM testing is safe and appropriate in healthy children and adolescents, providing the athletes are technically competent and closely supervised by qualified professionals (8). For youth with a low training age, or those who cannot consistently perform exercise techniques correctly, implementing multi-repetition RM protocols to evaluate muscular strength may be viewed as an alternative approach (21). The use of a higher number of repetitions (e.g. 10 RM) performed with sub-maximal loads to fatigue has allowed researchers to predict 1RM values in youth (7). However, these tests are less accurate for evaluating maximal strength (7), and increase the likelihood of accumulating large amounts of fatigue which could result in the breakdown of exercise technique and increased injury risk (21).

The isometric mid-thigh pull (IMTP) is a force-time diagnostic tool and is the most frequently implemented isometric strength test in the adult based literature (11, 17). Although the test itself is isometric, it has been significantly correlated to dynamic and athletic tasks in adults such as; vertical jump performance (17), sprint speed (32), agility (32), weightlifting movements (10), 1RM squat (17), and 1RM deadlift (4). However, further research is needed to examine the relationship between the IMTP and athletic tasks in children and adolescents. Kinetic measures including peak force (PF) and rate of force development (RFD) at different time sampling epochs are regularly reported (10, 11, 32), and have been established as highly reliable in adult populations (4, 5), albeit with greater variability shown for time dependent variables (23).

Very few studies have examined the reliability of force-time characteristics using IMTP protocols in youths. Dos'Santos et al. (6) found that PF and time-specific force values (30-250 ms) were highly reliable between and within-sessions in adolescent male soccer players. However, the potential effects of maturation on the reliability of IMTP performance remains unclear, as does the reliability of the protocol in young female athletes. Therefore, the purpose of this study was to examine the within- and between-session reliability of the IMTP in pre- and post-peak height velocity (PHV) female athletes.

METHOD

Experimental Approach to the Problem

This study used a within-subject repeated-measures design, to quantify the reliability of force-time characteristics of the IMTP in youth female athletes. Participants were grouped according to their maturational status (pre-PHV and post-PHV), and each sub-group followed the same testing procedures. Following a familiarization, each participant attended three different testing days (that were at least 24 hours apart), and performed three trials on each session.

Subjects

Thirty-eight female athletes (n = 19 pre-PHV, n = 19 post-PHV) aged 6–17 years agreed to participate in the study. PHV refers to the age at which a young athlete experiences maximum rate of growth during the adolescent growth spurt (24), and is commonly used as a measure of somatic growth (22). Standing height (m), sitting heights (m), and body mass (kg) were used to determine participants' maturity status using years pre- and post-PHV as outlined in the original research (27), as well as the percentage of predicted adult height (PAH) (18) as shown in *table 1*. While there is an error of approximately 6 months associated with the maturity offset, the significant differences in body mass, leg length, standing height between the two groups (*table 1*), combined with the additional maturity assessment using percentage of predicted adult height indicates that the determination of participants' maturation were relatively homogenous and accurate. Participants reported no injuries at the time of testing, were all regularly participating in sport, had a training age of less than 12 months, and no prior experience of the IMTP procedure. Participants were instructed to wear the same clothing and footwear to each testing session, and to refrain from strenuous activity 24 hours before testing. Parental consent and participant assent were obtained following ethical approval from the institutional research ethics committee.

Insert table 1 here

Procedures

Familiarization

Anthropometric data were collected including standing and sitting height using a stadiometer to the nearest 0.1 cm (SECA, 321, Vogel & Halke, Hamburg, Germany), and body mass using scales to the nearest 0.1 kg (SECA, 321, Vogel & Halke, Hamburg, Germany). All participants familiarized themselves with the IMTP testing protocol, which took place at the beginning of the first testing session. This involved each individual practicing the IMTP protocol until the lead researcher was satisfied with the athlete's technical competency. The force traces of the practice trials were observed for asymmetry and a stable weighing period prior to the pulling phase of the protocol.

All testing sessions took place in a laboratory using a custom built IMTP testing device (see figure 1) and two force plates sampling at a frequency of 1000 Hz (type 9287BA, Kistler Instruments AG, Winterthur, Switzerland). The athletes' second pull position for the power clean was then identified individually to optimize the production of maximal force and rate of force development (31). In line with previous research, the athletes adopted an IMTP set up position where; feet were hip-width apart, the bar was positioned at mid-thigh, the torso was upright with a neutral spine, and knee and hip angles were between 140 ± 5° and 135 ± 5°, respectively (4, 10, 11). The customized IMTP rig allowed for incremental bar height adjustments of 1 cm to accommodate athletes of different statures. All participants were instructed to stand bilaterally with one foot on each force plate, and once the athlete adopted the correct IMTP position, their hip and knee angles were verified and recorded using a handheld goniometer (plastic 12 inch, 66fit). Bar height was recorded using the measurement markings on the custom-made rig. Foot position was determined using a customized 2-figure grid reference system for each participant's heel and forefoot position to standardize foot position between testing sessions. Grip width was also established for standardization purposes and was measured using the difference between each index finger. Lifting straps were used to secure the athlete to the bar to reduce the likelihood of grip strength being a limiting factor for performance (11). Adhesive markers were placed on the grid references and bar for each young athlete to aid the setup process for each trial.

*** Figure 1 near here ***

Testing session

All participants performed a standardized 10-minute dynamic warm up before each testing session commenced, which included relevant activation and mobilization exercises, before advancing to 3 sets of 3 squat jumps, countermovement jumps and pogo hops. Each participants' specific measurements were replicated for each testing sessions to reduce the risk of measurement error associated with changes in athletes' posture (5). Once set up in their individualized IMTP position, participants were afforded one practice of the IMTP protocol sub-maximally and maximally, separated by 2 minutes rest time. The participants were then asked to step off of the force plates for zeroing purposes. Following a minimum of a 60 second rest period, the children were then ready to commence testing. Child friendly cues such as "*stand still like a statue*" were used to optimize the stabilization of body weight during the first second of each test, prior to initiating the pull. All subjects received the standardized instruction previously used for the IMTP protocol, "*pull as hard and as fast as possible until I say stop*," (5, 10, 11) and were instructed to pull equally with both hands. After a countdown of "*3, 2, 1* *pull*," participants worked maximally for the five second period of data collection. All participants completed three trials of the protocol and standardized verbal encouragement was provided throughout each trial. A minimum of two minutes of passive rest was given between trials to ensure sufficient recovery (12). Trials were discounted and repeated if the following occurred: the participant lost grip, a visible countermovement was present, or if the trial was not considered as maximal. In adult populations, a difference of > 250 N has resulted in the trial being repeated (11). Given the inherent variability in coordination for child populations (20), a difference greater than 15% of their peak force resulted in an additional trial being performed.

Variables

All isometric force-time curves were analyzed by the same researcher using custom built Labview (LVRTE2014SP1; National Instruments) analysis software, previously used in adult IMTP literature (11). For time-dependent variables, initiation of the pull was determined using the visual onset method, recommended in previous research (23). From the force-time data, the following variables were processed:

- *Absolute peak force (PF):* The maximum force (N) generated during the 5-second protocol.
- *Relative peak force (N/Kg):* The maximum force (N) generated during the 5-second protocol divided by the athlete's body mass (kg).
- *Force at 30, 50, 90, 100, 150, 200, and 250 milliseconds:* The force (N) produced at each time sampling interval calculated from the initiation of the pull.
- *Rate of force development (RFD):* The rate at which force is developed during a maximal contraction ($N \cdot s^{-1}$). RFD was calculated from the slope of the force-time curve during predetermined time bands; 0–50, 0–90, 0–100, 0–150, 0–200, and 0–250 milliseconds (11).

- *Peak rate of force development (pRFD)*: The pRFD is the highest RFD during a specific time sampling window (11). The 20-millisecond timeframe (pRFD20) was chosen for analysis owing to its superior reliability when compared to other sampling windows. (11)
- *Time to peak force (TPF)*: The total time (milliseconds) taken to reach the absolute peak force.
- *Time to peak rate of force development (TPRFD)*: The total time (milliseconds) taken to reach the peak rate of force development.

Statistical analyses

Descriptive statistics (means ± standard deviations) were calculated for all force and time variables for each group. The assumption of normality was assessed via the Shapiro-Wilk test. The change in the mean and a repeated-measures analysis of variance (ANOVA) was conducted to determine if there was any systematic bias between-session (session 1, 2 and 3) and within-session (trials 1, 2 and 3) for each group. Sphericity was assessed via Mauchley's Test and where violated, Greenhouse-Geisser was implemented. A Bonferroni post hoc test was used to identify pairwise differences. Between- and within-session random variability was determined using mean coefficients of variation (CV%) and intraclass correlation coefficients (ICC) to determine both absolute and relative reliability. Acceptable thresholds were determined using a CV of <10% (3). Ninety-five percent confidence intervals (95% CI) were calculated for all variables. Magnitudes of ICC were classified according to the following thresholds: >0.9 nearly perfect; 0.7-0.9 very large; 0.5-0.7 large; 0.3-0.5 moderate; 0.1-0.3 small (13). Noise:signal ratios were calculated for each variable using the typical error (noise) and the smallest worthwhile change (signal), with the smallest worthwhile change a factor of 0.2 of the between-participant standard deviation from consecutive trials, or across all trials to provide a mean ratio. Descriptive statistics and repeated-measures ANOVAs were computed using SPSS Statistics v.22, with statistical significance set at an alpha level of $p < 0.05$. ICC and CV% were calculated using an online spreadsheet run through Microsoft Excel for Mac version 15.35 (15).

RESULTS

Within-session descriptive statistics for each variable and associated reliability measures for pre- and post-PHV cohorts are presented in *table 2 and figure 2*. There was no systematic bias for any variables, and the random variation in absolute and relative peak force was slightly more reliable in post-PHV participants (CV = 5-6%, ICC = 0.91-0.96) compared to pre-PHV participants (CV = 8-10%, ICC = 0.87-0.97). Force measured at different time sampling intervals showed moderate reliability in the post-PHV cohort (CV% = 7.9-16.8%; ICC ≥ 0.77) but greater variation was evident in the pre-PHV group (CV% = 22.3-32.3%; ICC ≥ 0.78;). All time-related variables (RFD at various sampling intervals, pRFD, TPF and TPRFD) showed a greater range of ICC (0.29-0.9) and much larger variation across trials (CV% = 25.2-125.7%).

Insert table 2 and figure 2 here

Between-session descriptive statistics for each variable and associated reliability measures for pre- and post-PHV cohorts are displayed in *tables 3, and figure 3*. Between-session typical error of absolute and relative peak force was slightly more reliable in post-PHV (CV = 6.2-6.3; ICC ≥ 0.85) compared to pre-PHV (CV= 9.7-9.8%; ICC ≥ 0.71), while pre-PHV also demonstrated significant improvements in performance from trial 1 to 2, evidencing the presence of systematic bias. Force measured at each time sampling interval showed moderate reliability in the post-PHV cohort (ICC = 0.75-0.78; CV% = 11.7-22.2%) but greater variation was evident in the pre-PHV group (ICC = 0.83-0.86; CV% = 20.5-25.6%). All time-related variables (RFD at various sampling intervals, pRFD, TPF and TPRFD) showed a greater range of ICC (0.10-0.76) and much larger variation across trials (CV% = 31.6-143.1%).

Insert table 3 and figure 3 here

The noise:signal ratio data presented in *table 4* show that the majority of testing variables achieved a ratio of between 1.93-2.65, however, measures of absolute peak force achieved ratios of ≤ 1.33 in both pre- and post-PHV.

Insert table 4 here

DISCUSSION

The aim of this study was to determine the within- and between-session reliability of kinetic variables during the IMTP in pre- and post-PHV female athletes. Absolute and relative peak force were found to be reliable for both within- and between-sessions for both maturity groups. However, systematic bias was evident in the pre-PHV cohort between the first two testing sessions, which highlights the need for additional familiarization with younger and less mature female athletes. All other kinetic variables showed moderate to low reliability. Cumulatively, these findings confirm the reproducibility of the IMTP protocol for assessing maximal force production, and offer practitioners a viable option to assess maximal strength capabilities in female athletes pre- and post-PHV.

Non-significant changes in means, high ICCs and low CVs indicated strong within-session reliability for measures of absolute and relative peak force for both pre- and post-PHV athletes. While the means of all other variables did not change significantly within session, they did show much higher typical errors, especially RFD and pRFD and those variables that were time-dependent (TPF and TPRFD). This finding is commensurate with previous literature that has shown within-session RFD and RFD sampled at different time intervals to be less reliable than peak forces measured in the IMTP in 16-year old males (5). These findings would suggest that providing young athletes are afforded appropriate opportunity to familiarize themselves with the IMTP protocol, practitioners could use peak force data from a single trial. However, owing to the ease of administration and minimal time requirements for the IMTP, practitioners may wish to take a mean across multiple trials to reduce the level of noise, whereby random variation can be reduced by a factor of 1√number of trials (30).

Reliable testing protocols are required in order to confidently detect meaningful changes in performance. The current study reported strong between-session reliability for absolute and relative peak force as evidenced by high reproducibility and low variation for both absolute and relative measures of peak force in pre- (ICC = 0.71-0.95; CV = 9.2-9.7%) and post-PHV (ICC = 0.94-0.85; CV = 6.2-6.3%) female athletes. Similar to the within-session reliability, pre-PHV youth showed a higher degree of typical error in both absolute and relative measures of peak force across the three testing sessions in comparison to post-PHV athletes. Other researchers have reported slightly greater between-session reliability for measures of absolute peak force during the IMTP protocol in male adolescent soccer players (CV = 4.6% (5)) and in recreationally active males (CV = 3.1% (16)). Thus, it appears that between-session reliability measures of peak force improve with age, maturation and training history, especially those with greater experience of maximal lifts.

Considering maturation in the design of reliability studies is an important and often over-looked phenomenon. In the current study, pre-PHV showed greater variability in absolute and relative peak force than post-PHV athletes. Also, significant differences in mean peak force between the first two test sessions were evident, suggesting the presence of systematic bias within the less mature cohort. These data indicate that immature female athletes produce slightly less consistent peak force values during the IMTP, and require a greater amount of familiarization prior to testing. The greater degree of movement variability in less mature children has previously been shown in youth during jumping protocols (9), and is likely due to lower levels of coordination and immature prefrontal motor cortex activation resulting in more variable task execution.

Pre-PHV females had higher variability (CV = 19.3-36.3%) in force values at different sampling intervals than post-PHV athletes (CV = 10.2-23.2%), which supports the maturity-related trend shown for absolute and relative peak force. Both groups were less consistent and more variable at producing force across different sampling intervals compared to measures of absolute peak force which is consistent with previous IMTP research in adolescents (5), and adults (4, 11, 16). This suggests the ability to reproduce time-specific force values is naturally more variable, and could be due to vagaries in neuromuscular factors such as motor unit recruitment and discharge rates (23). Therefore, force at different sampling intervals should be used with caution, particularly in pre-PHV athletes.

Examining noise:signal ratios can increase practitioners’ confidence that true changes in performance will be detected (14). Although none of the time-specific force values achieved a noise value lower than the signal, all variables obtained overall noise:signal ratios of less than 2.2 and 2.7, in pre- and post-PHV athletes respectively. Absolute peak force was found to have the lowest noise:signal ratios for both pre- (1.19) and post-PHV (1.33) groups, and became slightly higher for relative peak force measures (pre-PHV = 2.02 and post-PHV = 2.53).

Consequently, a greater magnitude of change is required to exceed the typical error in these measures, and to accurately monitor changes in different force sampling intervals (14). Given the potential for large improvements in strength that youth can experience from growth, maturation and training (21), it is likely that changes observed in youth populations would surpass the smallest worthwhile change and exceed the random variation in these measures. For example, in the current study, a change in absolute peak force in excess of ~65 N in post-PHV female athletes would infer that a meaningful change has occurred as a result of training and/or maturation; changes of these magnitudes have been demonstrated previously in youth-based training studies (28). When choosing to use noise:signal ratios for force at different time sampling intervals, practitioners should consider the typical error of the variable to ensure the measure is sensitive enough to monitor changes in maturation or training. While this study is the first to report noise:signal ratios for IMTP variables in young females, the values are comparable to existing youth data on spatiotemporal measures obtained during maximal speed in boys (overall noise: signal ratios between 1.92-4.44) (26).

Finally, the between-session results from both group's time-dependent variables (RFD at various sampling intervals, pRFD, TPF and TPRFD) were deemed unreliable due to a large range in ICC (0.10-0.76) and high CV% (CV% = 31.6-143.1%). Similar findings have been reported in active children and adolescents for counter-movement jumps (9). It has been documented that RFD measures are inherently less reliable, particularly in multi-joint tasks due to more degrees of freedom and movement options available in the musculoskeletal system (23). While previous studies have reported high levels of reliability for time-dependent force measures in trained adult athletes (10, 11), the low reliability data from this study indicates that these variables are more unstable in youth.

PRACTICAL APPLICATIONS

There are a number of test protocols available to assess muscular strength capacity in youth; however, such protocols require a suitably robust level of technical competency for youth to safely perform them. As peak force measures from the IMTP have been validated against 1RM squat performance (17), the IMTP protocol offers practitioners a viable alternative for assessing maximal strength capacities in youth with lower levels of experience. Interestingly, while both absolute and relative peak force were found to be reliable, noise:signal values suggest these measures could be useful to practitioners in different ways. Absolute peak force was able to detect changes in maturation, due to the large differences observed in the measure from pre- to post-PHV. However, relative peak force values remained around 27 N/kg, suggesting this measure is less sensitive to changes in maturation but could be used to assess young female athletes' innate ability (e.g. talent identification or responses to training). Owing to the systematic bias in peak force shown by the pre-PHV group between the first two test sessions, additional familiarization is recommended for younger children to optimize between-session reliability. The IMTP protocol is deemed a highly reliable method of quantifying peak force capability in children and adolescents, and offers practitioners a safe and time efficient means of assessing maximal isometric strength capacities in young females.

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FIGURE LEGENDS

Figure 1. Isometric-mid thigh pull set up position lateral and anterior view.

Figure 2: Forest plots displaying coefficients of variation for within-session reliability: (A) pre-PHV athletes force at different time-sampling intervals (B) post-PHV athletes force at different time-sampling intervals (C) pre-PHV athletes force at different RFD epochs, and (D) post-PHV athletes force at different RFD epochs. Error bars indicate 95% confidence limits of the mean difference between trials.

Figure 3: Forest plots displaying coefficients of variation for between-session reliability: (A) pre-PHV athletes force at different time-sampling intervals (B) post-PHV athletes force at different time-sampling intervals (C) pre-PHV athletes force at different RFD epochs, and (D) post-PHV athletes force at different RFD epochs. Error bars indicate 95% confidence limits of the mean difference between trials.