Using the isometric mid-thigh pull in the monitoring of weightlifters: 25+ years of experience

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ABSTRACT

Currently, multi-joint, position-specific isometric tests (MJIT) are commonly used as part of the monitoring of an athlete's progress. Strong associations between isometric force-time curve parameters have been found. Perhaps the most commonly used test is the isometric mid-thigh pull (IMTP): the IMTP was created in the early 1990s and its use has grown considerably since that time. One sport in which it has been used extensively from the early 1990s to the present, particularly by the authors, is weightlifting. The relationships between weightlifting performance and IMTP force-time characteristics are quite strong, particularly for RFD. The IMTP is not only useful in assessing a weightlifter's performance but can also be used for monitoring fatigue.

Introduction

Monitoring an athlete's training and adaption to the training process provides valuable feedback for the weightlifting coach. Although there is some overlap, monitoring can be divided into assessment and feedback associated with fatigue management, or programme efficacy and adaptation.

In terms of adaptation, variables associated with maximum strength are particularly important for the assessment of the progress of weightlifting performance.[23,26] As strength can be defined as the 'ability to produce force', strength-related characteristics include an athlete's ability to produce maximum force, rate of force development (RFD), impulse (Force X Time), power and velocity of movement.[49] However, monitoring that requires excessive time commitments, or produces excessive fatigue, can be counter-productive to the goals of the monitoring programme. Multi-joint isometric testing (MJIT) represents one aspect of sport performance monitoring that can be time-efficient and is not overly fatiguing.[13,26,37] Thus, MJIT measurements, when properly performed using appropriate instrumentation (eg, isometric leg press, isometric testing rack, force plate, etc), can allow the coach and sport scientist to carefully evaluate a number of relevant variables such as the isometric peak force (IPF) and the isometric rate of force development (IRFD).

MJIT tests have some important characteristics and differences that make them preferable (at least at times) to the typical dynamic 1RM tests such as 1RM squats or cleans. These include:

1. The multi-joint isometric tests (MJITs) are relatively easy to administer and typically take substantially less time than 1RM tests

2. Based on our collective monitoring, research and coaching experiences, as well as input from sport coaches and athletes, less fatigue is reported after the MJIT compared to 1RM testing. This is supported by differences in neural activation, metabolic disturbances and tissue damage resulting from isometric versus dynamic muscle actions[6,29,32]

3. Although 1RM testing is considered safe and relatively injury-free – subjectively and based on injury reports from our laboratory – injuries are less frequent in MJITs when compared to 1RM testing. Over the last 12 years we have performed well over 2500 MJIT tests per year on several hundred athletes each year. To date, we have had three minor injuries (one isometric squat, and two isometric mid-thigh pulls [IMTP]) during that 12-year period. As with other exercises or tests, it is possible that MJIT could aggravate pre-existing injuries

4. A major advantage of MJIT is that maximum force production is less likely to be missed. It should be noted that, in typical dynamic 1RM tests, several factors potentially limit the ability of the athlete to produce a true maximum lift. First, the lifts are typically performed with free weights which have finite loading increments (ie, loading restrictions related to plate increments) – and therefore increases with each attempt will be limited by the smallest available load increment. Secondly, if the load of each attempt is not increased appropriately, as the athlete approaches their maximum, the athlete may under-perform as a result of mis-loading. One common scenario occurs when the final (or near final attempt) is too heavy and that attempt is barely missed – as a result of acute fatigue: decreasing the load a few kilograms still results in failure

5. Perhaps the most important advantage of MJIT is that there is a wealth of information concerning the athlete's abilities that can be obtained in addition to maximum strength. Force plates, load cells, and other force transducers allow the measurement of both the peak force values (representing maximum strength), average force and the time-dependent measures such as rate of force development and force at both early and late time periods after the initiation of the contraction.[11]

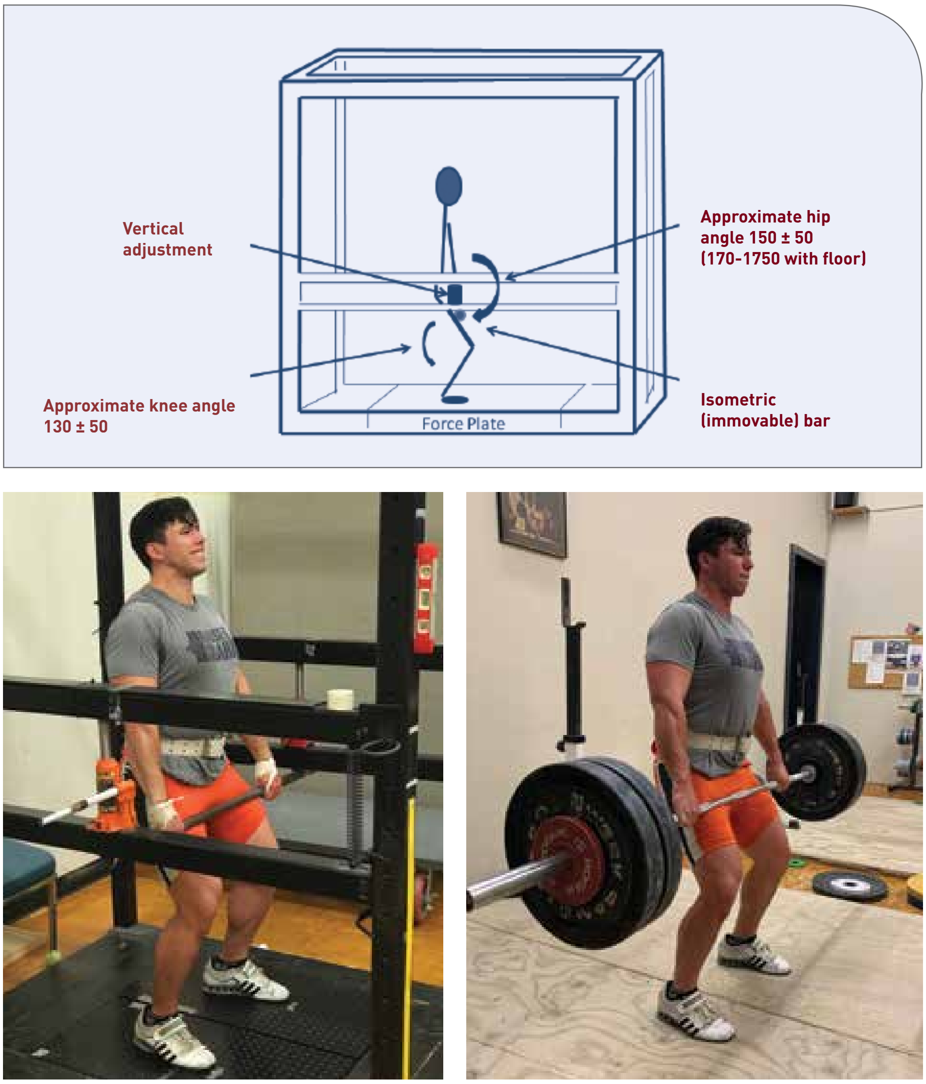


Figure 1a and 1b: 1a) Isometric mid-thigh pull (IMTP) testing device. Top: schematic isometric mid-thigh clean pulls. 1b) Bottom, photographic image of isometric mid-thigh clean pulls and power position in the clean.

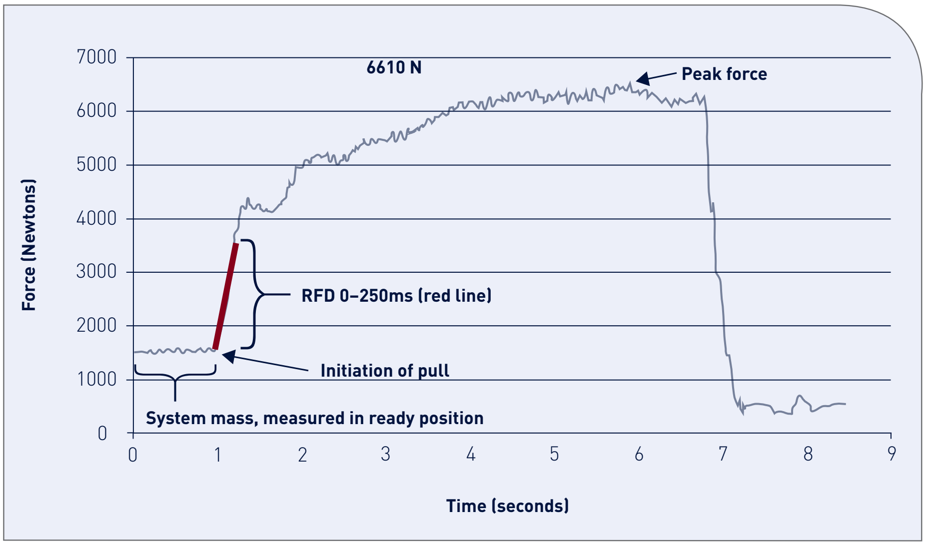
The most commonly used MJIT is the IMTP. After some initial testing of various MJIT by M H Stone during the late 1980s, the IMTP and the testing apparatus were created and developed in the early 1990s by M H Stone, H O'Bryant and G Haff at Appalachian State University. After considerable pilot testing, the use of an isometric rack, testing positions and comparison between isometric and dynamic measures was first presented to the scientific and coaching community in 1995.[21] The position (Figure 1a & b) for testing, was in part, created to 'mimic' the power position of a clean[22] and to provide the optimum mechanical advantage.[7,8,9,17,20] The apparatus, and testing position, has subsequently been used extensively to track a number of different sports,[4,5,27,31,44] particularly weightlifting.[23,26,47,48,51]

Injury resulting from testing is always a concern; however, in our experience, having performed many thousands of tests, we have found the injury rate to be very low; we have observed only two minor injuries in over 25 years of using the IMTP to monitor athletes. Neither injury interfered with daily routines or training. Indeed, the isometric pull is now commonly used throughout the world and reported injuries have been quite rare.

Methodology for measurements

As with any athlete monitoring test, the calibration, test environment, warm-up and commands should be standardised in order to enhance the tests' validity and particularly reliability (see Comfort et al[13] for additional details). Validity deals with the question: 'does the test measure what it is supposed to measure?' For MJIT this depends upon the force plate used and the quality of the force transducers in the plate. Validity and reliability can be enhanced by proper and frequent calibration. Calibration is typically performed by adding increasing incremental loads to the plate and comparing the recorded loading to the load being added. Calibration should be performed at the beginning and end of every testing session to ensure accurate data (for further discussion see Beckham et al[14]). Reliability is an estimate of the repeatability of a measure. Reliability is a measure of likely error and is basically associated with the amount of random and systematic error from the measurement process that might be embedded in the test scores. If a measurement is not reliable for a given goal of measurement, then it is not clear whether observed changes are due to error or adaptations, so generalisations/conclusions from the data cannot be made. Reliability is generally assessed with an intra-class correlation (ICC) and coefficient of variation (CV). For MJIT force and related variables reliability, the ICC should be above 0.75 and the CV less than 15%.[19] When appropriate instrumentation, calibration and instructions are used these reliability values are easily attained for most measured variables.[7,8,9,15] Based on our experience, further enhancement of reliability occurs among athletes who regularly engage in weightlifting pulling movements and/or are regularly exposed to IMTP testing.

Any warm-up used to prepare for the IMTP test should not be too strenuous as this can elevate fatigue and negatively impact the tests' results. The warm-up should also be specific to the test and include submaximal attempts for the mid-thigh pull (IMTP).



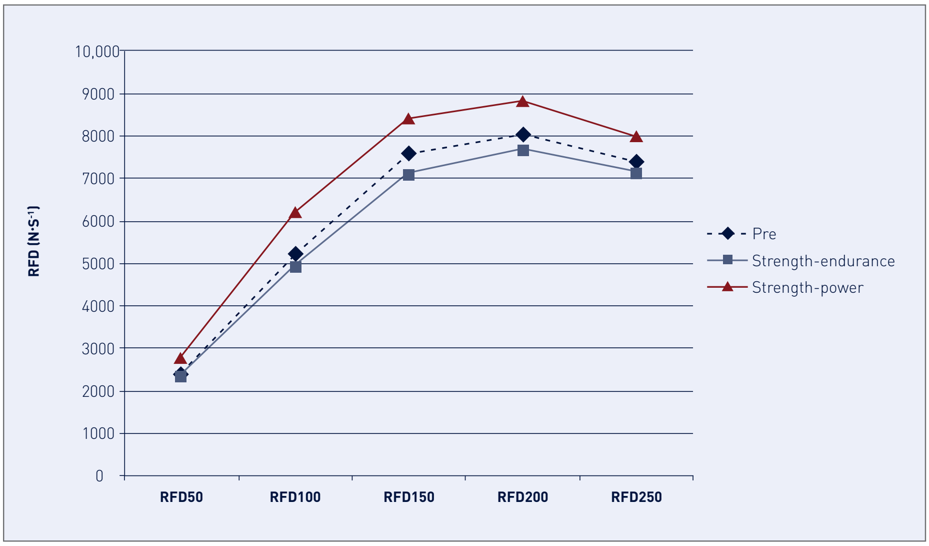


Figure 2. (top) IMTP Force-/time curve (with system mass and slack force)
Figure 3: (bottom) Rate of force development at four different time bands across time in response to different training blocks (modified from Suarez et al 2018)

Warm-up procedures used in our athlete monitoring programme are relatively simple and take no more than 5-10 minutes.[7,8,9,15] Typically, a general warm-up would consist of jumping jacks followed by light clean pulls from the power position.[15,26,24] This would be followed by a specific warm-up of IMTPs at a perceived 50 and 75% maximum effort.[20]

Following a standardised warm-up, each athlete should be positioned in a custom-built power rack with an affixed bar (Figure 1a and b). The internal knee and hip angles can be measured manually using a goniometer and should be approximately 125-145° and 140-150° respectively, with a small amount of tension to remove system slack.[13] Depending upon the athlete, the exact knee and hip angle may vary slightly and some angle adjustments may be necessary in order to optimise the individual athlete's pulling position.[9] Similar to teaching the power position to an athlete,[25] posture should be individualised; however, the athlete's IMTP position should be consistent between testing sessions.[9,20] For weightlifters in particular, the position should mirror the power position (ie, start of the second pull) in the clean.[8,23,25]

The isometric testing rack can use a single or more appropriately dual force plate testing system that allows testing for asymmetrical pulling movements. As the RFD can be quite high, the sampling rate of a minimum of 1000 Hz is typically used in order to ensure that no pertinent data is missed.[9] An important factor for the IMTP is to make sure that the strength of the hands does not become a limiting factor. Lifters can be secured to the bar using weightlifting straps and athletic tape (Figure 1b) in order to eliminate grip strength as a confounding variable during testing.[22] Prior to maximal effort trials, a 50% and a 75% warm-up effort should be completed, separated by sixty seconds of rest. Three minutes of rest should be given following the final warm-up effort. Each athlete should complete at least two maximal-effort IMTP trials and the athletes should be instructed to 'pull as fast and as hard' as they can. Additional trials should be completed if the isometric peak force (IPF) differs between trials >250 N or if there is a >200 N counter-movement in any trial. Verbal encouragement should be provided during every IMTP effort. Three minutes of rest is typically given between trials to help ensure a maximum effort for all trials. Kinetic data can be processed/analysed using commercially available software such as ForceDecks (Brisbane, Australia) or by using custom designed programmes (eg, Lab View, National Instruments, Austin, Texas). The two best trials (best = highest PFs and no 'issues' with test and/or data) should be averaged for data analysis: by averaging the trials a clearer 'picture' of the athlete's typical capabilities during a specific time frame can be made and the reliability of the test, especially the CV, can be enhanced.[43]

Analysis of the resulting force time curve can provide a considerable amount of data that will aid in ascertaining the athlete's level of progress. A typical IMTP force-time curve is shown in Figure 2. Several key factors can be derived from the force-time curve. IPF has been shown to strongly associate with weightlifting ability.[8,22,23,26,48] Perhaps the most sensitive measure for assessing both adaptation and fatigue is the RFD.[26,37,48] Peak RFD is calculated using a 'sliding window' of predetermined length (eg, 5ms), over which RFD is calculated (ΔForce/Δtime), and the highest RFD value from any of the windows is selected.[24] Although peak RFD was used in initial studies,[22] it is not always reliable, whereas RFD over specified time bands (eg, 0-200ms, 0-250ms) typically show good reliability.[24]

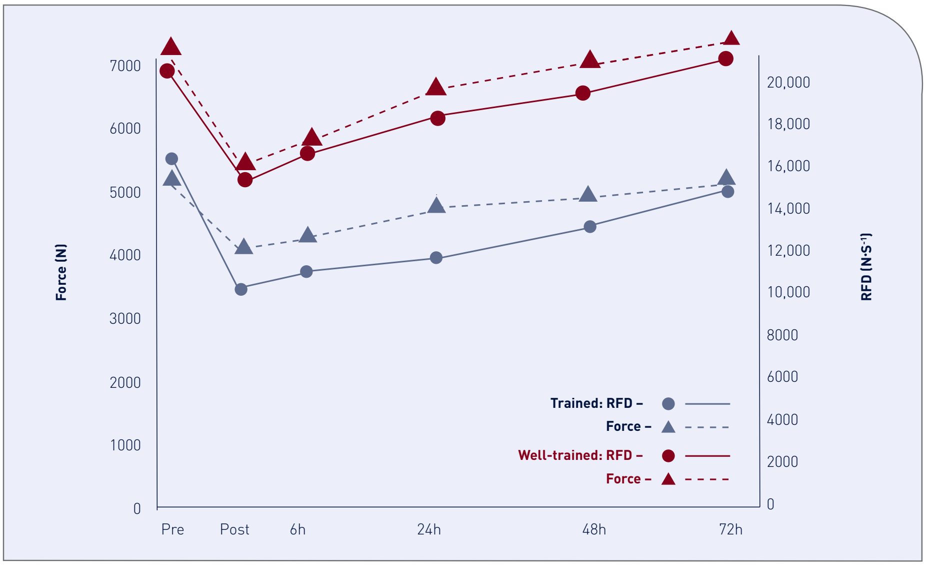


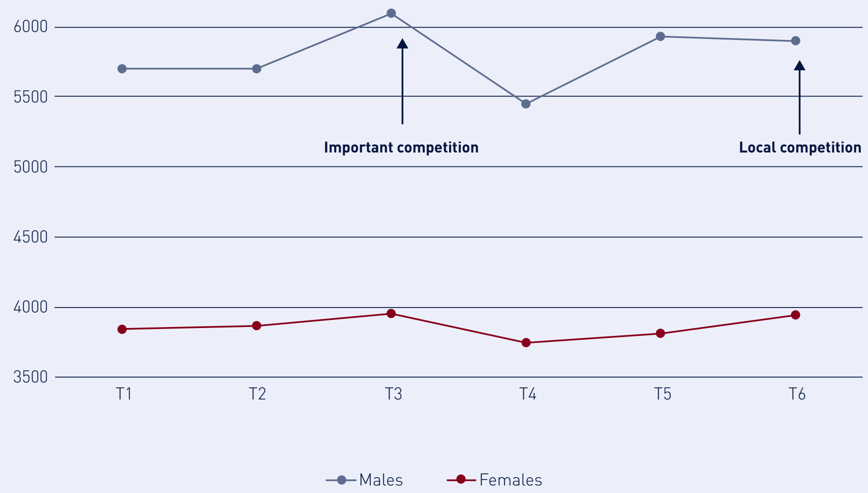
Figure 4. Recovery of isometric peak force and RFD: Typical recovery pattern after training session (squats and push press for 5 x 5 at 95 – 100% relative intensity for sets and repetitions): well-trained athlete recovers faster

Software packages may use peak RFD, time-banded RFD, or both, so it is important for the coach to be sure which 'type' of RFD is being outputted. Figure 3 shows the RFD at four different time bands (time from 0 to a specified time); 0-50 ms, 0-100 ms, 0-150 ms, 0—200 ms, 0-250 ms. RFD for these time bands can provide unique insights into various phases of a snatch or clean pull.[20,8,30]

Use of the IMTP as a monitoring tool

As previously noted, appropriate monitoring can be used to gauge fatigue or measure programme efficacy and adaptation. From a fatigue management aspect, the quantification of fatigue can be important both from a load adjustment and training prescription aspect, as well as providing training background injury risk. Often, due to its multi-factorial nature, a variety of monitoring tools are used to estimate the degree of fatigue. Tests have included serum markers of muscle damage, cytokine and endocrine responses, immune status and reactive oxygen species concentrations, neuromuscular function, and recovery questionnaires.[6,35,42,52] Although these tests often provide data-rich information, the regular longitudinal measurement of most of these markers is not typically feasible due to cost and time constraints. Finding a single measure that is indicative of all fatigue manifestations would be quite advantageous, but it is also unlikely.[45,37] However, of the markers currently used, longitudinal recovery of neuromuscular function (NF) is likely the most practically viable means, as most NF measurements, particularly the IMTP, produce relatively little fatigue and have a low potential for injury. Furthermore, NF measurements are relatively easy to perform/assess and these measures are associated with training load alterations and sport performance injury risk.[3,26,36,37]

The two most common IMTP measures used for monitoring are IPF and IRFD. IPF is unlikely to be very useful for fatigue management as maximum strength (reflected by IPF) is not particularly sensitive to fatigue and only shows substantial decreases when accumulative fatigue is quite severe.[26,37] On the other hand, RFD is very sensitive to fatigue and can be a valuable part of a fatigue management plan. Another potential advantage of explosive strength force-time measures (eg, RFD bands) using the IMTP is a better understanding of the neural and contractile mechanisms associated with neuromuscular fatigue;[1,2,18] particularly when using multi-joint measures which can provide greater ecological validity for sports especially weightlifting.[26,34,41] It appears that early-phase RFD (<75 ms) is primarily influenced by neural and intrinsic muscle properties, whereas later phases (>75 ms-300 ms) are regulated primarily by contractile components and maximum strength.[1,2,18,34,41,48]



Males = 4; Females = 3

T1: AR baseline - after a one-week low volume and low-moderate intensity active rest block

T2: SE: after a four-week high volume low to moderate intensity block

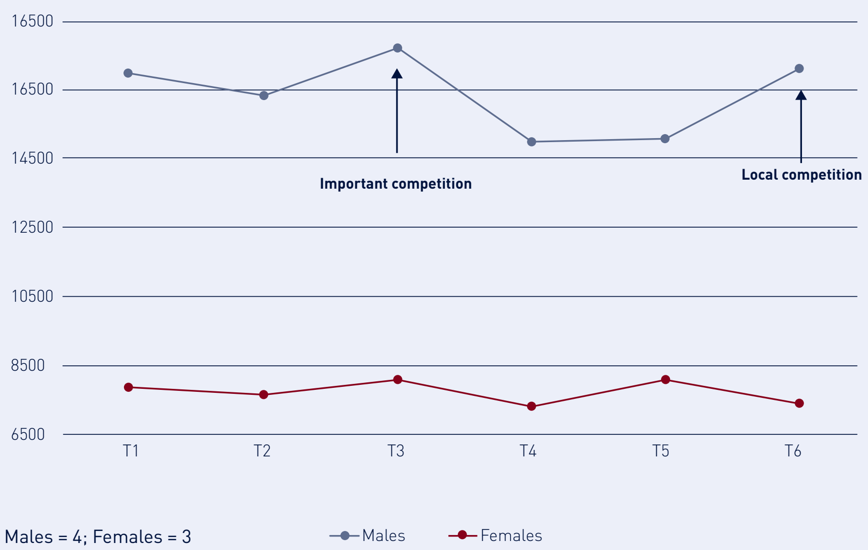
T3: sP: after a four-week block moderate to low volume strength-power phase (with a one-week over-reach block with increased volume emphasising increase maximum strength) follow by a taper emphasising power and emphasising complete lifts (snatch and clean & jerk)

T4: AR: after a two-week very low volume and intensity active rest block

T5: S: after a four-week block emphasising increased maximum strength

T6: Sp: after a three-week block (one-week over-reaching with increased volume emphasising increase maximum strength) and two-weeks of strength+power combination. Volume moved from high to low.

Figure 5.(top) Isometric peak force (IPF) across time. Modified from Hornsby et al 2017
Figure 6. (bottom) Isometric rate of force development (RFD; 0- 200ms) across time. Modified from Hornsby et al 2017



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T5: after a four-week block emphasising increased maximum strength

T6: after a three-week block (one-week over-reaching with increased volume emphasising increase maximum strength) and two-weeks of strength+power combination. Volume moved from high to low.

For example, Figure 3 shows the IMTP-derived RFD resulting from two different consecutive phases of training in a group of college age weightlifters of USA national calibre (n= 11; six males and five females). The first training phase (strength-endurance) was the initial block of the training stage and consisted of high volumes of low to moderate relative intensities. The second phase of training (strength-power block) consisted of moderate volumes at higher relative intensities, RFD was measured at the five different time bands before and after each block. Note (Figure 3) that RFD was depressed after the initial strength-endurance block (≈4 weeks), but interestingly IPF was little altered during this phase.

It should be realised that a SE block (high training volume) often results in substantial accumulative fatigue as noted by alterations in subjective perceptions, subtle hormonal alterations and depressed NF, particularly as reflected by RFD and higher velocity/power movements such as weighted vertical jumps.[26,39] After the second block, RFD increased substantially above baseline testing, reflecting both the reduction in volume (and reduced accumulated fatigue) and the adaptive process. Similar findings have been consistently observed in our laboratory with a variety of advanced/well-trained athletes, particularly strength-power athletes.[26,38,48] So, it should be noted from this example that RFD can reflect both long-term/accumulated fatigue and adaptation to training.

RFD can also be used to track short-term recovery from training.[37] NF can require up to 96 hours to return to baseline after a strenuous training session or competition among rugby and soccer players.[28,16,37,53,54] Similar observations for RFD have been observed after weight training sessions in our laboratory. Although IPF can be considerably depressed immediately after a high volume or very high intensity weight-training session it typically returns to baseline within 24 hours among well-trained lifters (slightly longer in lesser trained athletes). Although there are differences in individual recovery IPF abilities, RFD can require substantially more time, potentially indicating a relatively long-lasting neural disturbance (Figure 4). So, when examining programme efficacy/

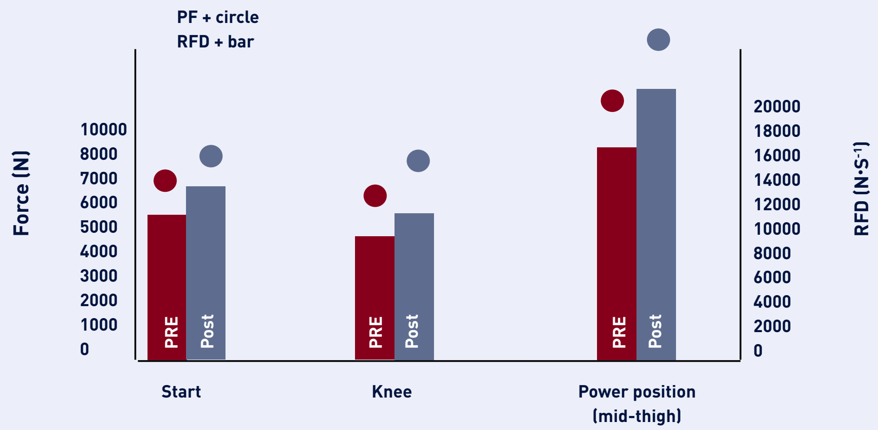
adaptation effects using isometric RFD (or other NF tests), a reasonable recovery period should take place before measurement, especially if the last training session was reasonably strenuous. Furthermore, if an athlete is not showing recovery within a reasonable time (≈ 48-72 hr.) then training alterations should be considered.

A major reason for the use of monitoring with athletes is programme efficacy: this basically deals with whether the programme worked in the anticipated manner – or not. As previously noted, the two most commonly used force-time characteristics derived from the IMTP have been PF and RFD. Figures 5 and 6 depict both IPF and RFD behaving as expected.[26] PF showed little alteration from baseline (T1) after the initial SE high volume block (T2), but an increase after T3 when strength and power were emphasised. After the active rest block (T4), maximum strength (IPF) again showed an expected reduction as a result of decrease volume and intensity of training (ie, detraining). IPF was substantially increased after T5 (emphasis on maximum strength) and was maintained through T6.

RFD also followed the expected alterations across time. Note the fall in RFD after the high-volume strength endurance block (SE) agreeing with the observations of Suarez et al.[48] After the sP block with an over-reaching phase followed by a substantial volume taper, RFD was at its highest value just before the most important competition of the year for these lifters. As expected (among male lifters), detraining caused a marked decrease in RFD (T4) followed by an increase as emphases in training again returned to strength and power (T5–T6). There was an unexpected drop in RFD among the female lifters at T6: exactly why this happened is not completely understood – yet.

Programme efficacy monitoring is especially important as it can identify and quantify:

1. Differences between males and females – differences could make it necessary to consider somewhat different training programmes for males and females
2. Although not observed in the study by Hornsby et al,[26] marked differences in the pattern of adaptation can be noted among different athletes,[40] which may mean some alteration in training for those individual athletes would be necessary
3. Group differences deviating from the expected should entail a re-consideration of training methods.



Start: bar at the position of weights on floor with 20 kg plates
Knee: bar at mid-patella height
Power: bar at IMTP height (power position)

Figure 7. IPF and IRFD at different positions for the clean

Another variation of the IMTP would be to use a number of different pulling positions. For example, clean pulls from the starting position, pulls from the bar at knee level, and pulls from the power position. Figure 7 represents the typical pattern for IPF and IRFD for a reasonably advanced lifter (eg, USA American Open Championship level) at these three positions. Similar patterns would be noted for the isometric snatch pull. Note with training both IPF and IRFD can be improved. However, depending upon the position emphasis in training, greater or lesser improvements for that position can be made.

Nuances and details

Although the IMTP is not particularly fatiguing or injurious, it may not always be feasible to perform the complete test close to an important competition. It should be noted that RFD is quite sensitive to both fatigue and adaptation – if IRFD is the primary variable for consideration then the pulling time can be decreased to approximately two seconds. All pertinent IRFD bands can be captured in this time frame. This reduction in pulling time may also decrease both fatigue and injury potential (all injuries reported have been near peak force). One possible scenario would be to perform the complete test only at the beginning and end of the competitive season (or beginning and end of a macrocycle (Stage) and to perform the RFD shortened test (2 s pull) more often; the shortened less fatiguing test can be performed closer to the competition.

As heavier athletes can typically produce more absolute force than smaller athletes, comparison between different size athletes can require scaling in order to reduce the effect of differences in body size. Performances can be scaled by dividing a result by body mass, traditional allometric scaling,[33] or other methods such as the Sinclair Coefficient.[46] Traditional allometric scaling attempts to account for the increase in maximum strength as body mass increases by using the two-thirds power law: isometric force · bodymass$^{-0.67}$. Although several methods of scaling the results obtained from an IMTP have been tried, it is important to note that all scaling methods have limitations,[14,46,50] but traditional allometric scaling is generally efficacious.[10,33,50] Allometric scaling likely allows for a better (more fair) assessment compared to simply dividing an athlete's strength by their body mass (PF/ body mass), due to strength rising at slower rate than body mass (eg, a 100kg athlete squatting 2.5 times body mass is more impressive than a 50kg athlete squatting 2.5 times body mass).[50]

Scaling strength is useful for various sports and a particularly important consideration for strength-based weight class sports such as weightlifting. For example, using the IMTP, an IPF of 5000N performed by an athlete weighing 100 kg would produce an allometrically scaled peak force (IPFa) of 229. This can be compared to an athlete weighing 81 kg producing an IPF of 4500 N and an IPFa of 237. So, the smaller athlete is actually stronger on a relative basis. Although RFD is not substantially affected by body mass, RFD can also be scaled. Typically, this is accomplished by dividing the RFD by IPF[1] or dividing the RFD by the allometrically scaled body mass. Importantly, by using these scaling method, athletes of different absolute strength and RFD levels can be compared and longitudinal comparisons can be made as athletes change body weight classes.

The IMTP takes approximately 10-20 minutes per lifter counting warm-up. Test time, overall efficiency and reliability can be greatly improved by giving athletes and coaches/sport scientists several practice sessions before initiating the monitoring programme.

Summary

MJITs can be quite efficacious and time-efficient. Due to the positioning specificity, for many sports, particularly weightlifting, the isometric mid-thigh pull (IMTP) is especially useful, both for regularly monitoring athletes as well as for research purposes.

For coaches, monitoring is especially important in that it provides the coach with pertinent information about their athletes, allowing coaching decisions that may not be possible otherwise. Although there is some overlap, monitoring can be divided into fatigue management and programme efficacy. The IMTP and tracking IPF – and especially IRFD – can provide insights into acute and chronic fatigue and long-term adaptations not otherwise possible.

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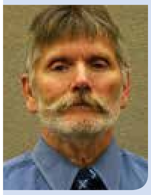

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Michael H Stone, PhD, is currently the exercise and sports science laboratory director and the PhD coordinator in the department of sport, exercise, recreation and kinesiology at East Tennessee State University (ETSU). He was a USA national level weightlifter during the 1970s and 80s. From 1999-2001 he was chair of sport at Edinburgh University. Prior to joining ETSU, he was the head of sports physiology (2001-2005) for the USOC. Dr Stone's service and research interests are primarily concerned with physiological and performance adaptations to strength/power training. He has more than 240 publications in reviewed journals, co-authored two textbooks dealing with strength and conditioning, and has contributed chapters to several texts in the areas of bioenergetics, nutrition, and strength/power training. Dr Stone was the 1991 NSCA Sports Scientist of the Year and was awarded the NSCA Lifetime Achievement Award in 2000. He was the recipient of the ETSU award for Distinguish Research Faculty in 2008, and was awarded the 2012 'Doc' Councilman award for application of sport science to sport by USA Weightlifting. He is a Fellow of the UKSCA and NSCA and is certified by the UKSCA (ASCC), NSCA (CSCS) and USA Weightlifting. He has been the strength and conditioning coach for a number of different sports and has coached several international and national level weightlifters (including one Olympian) and throwers in both the United States and Great Britain.

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