

**Manchester  
Metropolitan  
University**

---

Comfort, P, Dos'Santos, T, Beckham, GK, Stone, MH, Guppy, SN and Haff, GG (2019) Standardization and methodological considerations for the isometric midhigh pull. *Strength and Conditioning Journal*, 41 (2). pp. 57-79. ISSN 1524-1602

---

**Downloaded from:** <https://e-space.mmu.ac.uk/626030/>

**Version:** Accepted Version

**Publisher:** National Strength and Conditioning Association

**DOI:** <https://doi.org/10.1519/SSC.0000000000000433>

**Usage rights:** Creative Commons: Attribution-Noncommercial 4.0

Please cite the published version

<https://e-space.mmu.ac.uk>

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/328498794>

# Standardization and Methodological Considerations for the Isometric Midhigh Pull

Article in *Strength and conditioning journal* · October 2018

DOI: 10.1519/SSC.0000000000000433

CITATIONS

16

READS

684

6 authors, including:



**Paul Comfort**

University of Salford

215 PUBLICATIONS 2,264 CITATIONS

[SEE PROFILE](#)



**Thomas Dos'Santos**

Manchester Metropolitan University

66 PUBLICATIONS 508 CITATIONS

[SEE PROFILE](#)



**George Beckham**

California State University, Monterey Bay

40 PUBLICATIONS 466 CITATIONS

[SEE PROFILE](#)



**Michael Henry Stone**

East Tennessee State University

427 PUBLICATIONS 13,307 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



High Volume Resistance Training and its Effects on High Intensity Exercise Endurance [View project](#)



Thesis [View project](#)

## Standardization and methodological considerations for the Isometric Mid-Thigh Pull

Paul Comfort<sup>1,#</sup>, Thomas Dos'Santos<sup>1</sup>, George K. Beckham<sup>2</sup>, Michael H. Stone<sup>3</sup>, Stuart. N. Guppy<sup>4</sup>, G. Gregory Haff<sup>4</sup>.

<sup>1</sup> Directorate of Sport, Exercise and Physiotherapy, University of Salford, Salford, Greater Manchester, UK

<sup>2</sup> Kinesiology Department, California State University, Monterey Bay, Seaside, CA.

<sup>3</sup> Center of Excellence for Sport Science and Coach Education, Department of Exercise and Sport Science, East Tennessee State University, Johnson City, TN.

<sup>4</sup> Centre for Exercise and Sports Science Research, Edith Cowan University, Joondalup, Australia

#Corresponding Author – [p.comfort@salford.ac.uk](mailto:p.comfort@salford.ac.uk)

1 **Abstract**

2 The isometric mid-thigh pull (IMTP) is commonly used to assess an athlete's force  
3 generation ability. This test is highly reliable and is simple and relatively quick to perform.  
4 The data that can be determined from the force-time curves generated by the test have been  
5 shown to be closely related to performance capacities in a variety of dynamic athletic tasks.  
6 However, within the scientific literature there are inconsistencies in the data collection  
7 procedures and methods used for data analysis that may impact the resultant output and the  
8 ability to compare and generalize results. Therefore, the primary aim of this review is to  
9 identify the differences in IMTP testing procedures and data analysis techniques, while  
10 identifying the potential impact this may have on the data collected. The secondary aim is to  
11 provide recommendations for the standardization of testing procedures to ensure that future  
12 IMTP data is of maximal benefit to practitioners and researchers.

13

14 **Keywords:** Force; Rate of Force Development; Posture; Isometric Strength

## 15 **Introduction**

16 Maximal strength underpins performance in many athletic tasks (15, 55, 63) and as such,  
17 monitoring strength, usually by repetition maximum (RM) testing, is commonly performed  
18 by practitioners and researchers. While RM testing is reliable (12, 24, 28), it can be perceived  
19 as fatiguing, posing an increased potential for injury risk, and only providing information  
20 related to the maximal load lifted. In contrast, isometric testing, such as the isometric mid-  
21 thigh pull (IMTP), is potentially safer (18), less fatiguing, and allows for the quantification of  
22 peak force (PF), force at a variety of epochs, and can provide several measures of the rate of  
23 force development (RFD) (11, 21, 26, 30, 32, 33). The diagnostic ability of these measures  
24 may be of importance when considering time constrained tasks within sports, such as  
25 jumping, sprinting and change of direction. Importantly, the IMTP has been shown to be  
26 highly reliable both within and between sessions, with low variability and low measurement  
27 error (8, 11, 18, 24, 26, 27, 32).

28 Performance in the IMTP has been associated with performance in numerous athletic tasks  
29 (7, 18, 30, 33, 40, 41, 45, 46, 49, 59, 64, 66, 67, 69, 72, 73). Specifically, absolute PF has  
30 been associated with weightlifting performance (7, 30), 1RM squat and power clean (45-47,  
31 49, 59, 69, 73), 1RM deadlift (18), vertical jump performance (39-41, 53, 60, 64, 67), short  
32 sprint and change of direction times (59, 64), sprint cycling performance (60), and throwing  
33 performance (72) (Table 1). In contrast, West et al. (71) reported no meaningful relationships  
34 between absolute PF and short sprint times or jump height, although they did observe large  
35 correlations between relative PF (PF/body weight) and these variables in rugby league  
36 players. Similarly, Nuzzo et al. (49) reported only a small relationship between absolute PF  
37 and jump height but a large relationship between relative PF and jump height (Table 1). The  
38 range of associations between PF and performance in other tasks is summarized in Figure 1.  
39 Researchers have also reported relationships between allometrically scaled PF and

40 performance in athletic tasks (60, 72), demonstrating similar correlations to those observed  
41 when ratio scaling is used (60).

42 [Insert table 1 about here]

43

44 [Insert figure 1 about here]

45

46 Another way to examine the isometric force-time curve is to measure force at specific time  
47 epochs (e.g. 50-250 ms). It has been reported that these time specific forces are associated  
48 with squat jump (SJ) and countermovement jump (CMJ) height (force at 50-, 90, 250 ms)  
49 (41), weightlifting performance (force at 100-, 150-, 200-, 250 ms) (7) and 1RM back squat  
50 (90-250 ms) (69). Additionally, allometrically scaled force at 150 ms was reported to be  
51 related to mean and maximum club head speed during a golf swing (42), with allometrically  
52 scaled force at 50-, 90- and 250 ms also related to jump performance (41) (Table 2). In  
53 contrast, however, force at 30-250 ms was not related to 1RM deadlift performance (18).

54

55 [Insert table 2 about here]

56 Equivocal results regarding the relationships between measures of RFD and performance in  
57 dynamic athletic tasks have been reported in the scientific literature. When examining how  
58 the RFD is quantified two main methods exist within the literature (32). The first method is  
59 to quantify the peak RFD (PRFD) that occurs during the IMTP with a predefined moving  
60 window, most typically lasting between 2-40 ms (32) (Table 3). When this method is utilized  
61 for analyzing the force-time curve conflicting results exist within the scientific literature with

62 some authors reporting significant relationships between the RFD and dynamic performance  
63 activities (30, 33, 39, 41), while others report no meaningful relationship with 1RM  
64 performance (7, 45-47), or SJ and CMJ performances (40, 49, 67). These difference may be  
65 attributable to the moving window, with Maffiuletti et al. (43) cautioning against the use of  
66 short windows (e.g. 2 ms) as they may be too sensitive to unsystematic variability and  
67 therefore less reliable. The second method for evaluating the RFD is to examine time  
68 dependant epochs (32). The use of time dependent epoch has been shown to be an effective  
69 method for examining the RFD during the IMTP and relating it to various sports performance  
70 tasks. For example, Spiteri et al. (58) report that athletes who produce higher RFD to 90 ms  
71 and 100 ms are able to demonstrate faster agility times during a 45 ° cutting task. One  
72 possible explanation why some RFD measures relate to dynamic performance activities and  
73 others do not is the method of calculation and reliability of the method. For example, Haff et  
74 al. (32) have shown that the only PRFD measure that is reliable is when a 20 ms moving  
75 window is used, supporting previous suggestions by Maffiuletti et al. (43). Conversely,  
76 using time dependent epochs such as 0-90 ms, 0-150 ms, 0-200 ms and 0-250 ms to calculate  
77 the mean RFD across the specific duration produces much more reliable results and generally  
78 have better relationships to dynamic performance measures. Therefore, it is generally  
79 recommended that using time specific RFD epochs is warranted when using the IMTP as a  
80 performance diagnostic tool (32).

81

82 [Insert table 3 about here]

83 Another method for analysing the force-time curve derived from an IMTP is to examine the  
84 isometric impulse (67, 68). For example, impulse values across different epochs (0-100, 0-  
85 200 and 0-300 ms) have been associated with 5- and 20 m sprint times as well as 505 change

86 of direction times (64), peak force and power during the SJ and CMJ (68) (Table 4). While  
87 determining the isometric impulse of various epochs within the force-time curve achieved  
88 during the IMTP yields useful information much more research is needed to understand how  
89 best to utilise this measurement in a sports performance monitoring program.

90

91 [Insert table 4 about here]

92 The PF achieved during the IMTP has also been used to monitor adaptations to training (5,  
93 36, 50, 51, 57, 70, 74), with some authors also including RFD (36, 51, 52, 74). PF and peak  
94 RFD have also been used in an attempt to identify levels of fatigue or recovery (4, 29, 35,  
95 44). More recently researchers have started to investigate the potential of the IMTP to  
96 investigate between-limb asymmetries, using dual force platforms (1-3) and a unilateral  
97 stance IMTP (25, 65). Additionally, the PF during the IMTP has been divided by the PF  
98 during a SJ or CMJ, to calculate the dynamic strength index (DSI; ratio of PF during the CMJ  
99 or SJ and IMTP PF), in attempt to identify if an athlete needs to focus more on maximal force  
100 production or rapid dynamic force production (14, 52, 54, 56, 66).

101

## 102 **Variation in Testing and Data Analysis Procedures**

103 Unfortunately, there is substantial variation across testing protocols reported within the  
104 scientific literature, including differences in knee and hip joint angles (120-150° and 124-  
105 175°, respectively), sampling frequency (500-2000 Hz), pull onset identification thresholds  
106 including absolute (20-75 N) and relative (2.5-10% body weight) threshold values, and  
107 smoothing and filtering approaches, with some authors not stating hip angles, thresholds or  
108 filtering procedures (Table 5). In addition, if practitioners or researchers are intending to use



109 published values for comparison they should be mindful that some data is presented as net  
110 force (gross force – body weight) while others report gross measures, along with ratio and  
111 allometric scaling used in some studies. These two latter approaches may impact the results  
112 less, as allometric scaling uses an exponent related to body mass (13) although allometric  
113 scaling will reduce the resultant values compared to ratio scaling, with greater variation  
114 introduced depending on the exponent used (Table 5).

115

116 [Insert table 5 about here]

117

118 Numerous authors have suggested that the posture adopted during the IMTP should replicate  
119 the start of the second pull phase of the clean, (30, 31, 33, 60); however, only two studies  
120 have actually assessed the participants knee joint angles during the clean and then adopted  
121 these angles during the IMTP (30, 31). This is most likely due to time and practicality of  
122 assessing specific joint angles during the clean prior to performing the IMTP, especially  
123 when assessing large squads of athletes. Interestingly, hip joint angles were not reported  
124 within these two studies (30, 31).

125 Due to the variety of knee and hip joint angles reported within the literature, Comfort et al.  
126 (11) investigated a range of knee ( $120^{\circ}$ ,  $130^{\circ}$ ,  $140^{\circ}$ ,  $150^{\circ}$ ) and hip ( $125^{\circ}$ ,  $145^{\circ}$ ) joint angles,  
127 along with self-selected posture (knee  $133 \pm 3^{\circ}$ , hip  $138 \pm 4^{\circ}$ ) based on the athletes preferred  
128 position to start the second pull of a clean, which is what the posture adopted during the  
129 IMTP was originally based on (33). The results of the study indicated that there were no  
130 significant or meaningful differences in PF, PRFD or impulse between postures, although the  
131 preferred (self-selected) posture demonstrated the highest reliability and the lowest

132 measurement error. In contrast, Beckham et al. (6) found that powerlifters produced greater  
133 PF during an isometric testing with a vertical torso compared to a deadlift-specific body  
134 position at the same bar height, described as being a “relatively straight legged position and  
135 somewhat bent over the bar”. The authors suggested that the upright position may have  
136 provided a mechanical advantage and a posture more optimal for force production against the  
137 bar. In another study, Beckham et al. (8) compared the effects of different hip joint angles  
138 ( $125^\circ$  vs.  $145^\circ$ ), while standardizing the knee joint angle ( $125^\circ$ ) reporting meaningful and  
139 significantly higher PF and force at different epochs (50, 90, 200, 250 ms) in the more  
140 upright ( $145^\circ$ ) position, especially in subjects with greater experience in performing  
141 weightlifting exercises and their derivatives, in contrast to Comfort et al. (11). Interestingly,  
142 Beckham et al. (8) reported small changes in joint angles throughout the execution of the test  
143 and based on these observations recommend that in the future researchers and practitioners  
144 should adopt standardized knee and hip angles of  $120\text{-}135^\circ$  and  $140\text{-}150^\circ$ , respectively.

145 More recently, Dos’Santos et al. (26) compared hip joint angles of  $145^\circ$  and  $175^\circ$  with a  
146 standardized knee joint angle of  $145^\circ$ , finding greater time specific force values and RFD at  
147 predetermined epochs, with a  $145^\circ$  hip angle (Table 5). The hip angle of  $175^\circ$  previously  
148 reported by Kraska et al. (41) and replicated by Beckham et al. (6) actually refer to trunk  
149 angle relative to vertical, to ensure an upright trunk (forward lean of  $5^\circ$  from vertical),  
150 exhibiting an upright trunk as previously described (30, 31, 33, 60) rather than a  $175^\circ$  hip  
151 angle as used by Dos’Santos et al. (26). The authors of a recent meta-analysis also highlight  
152 the fact the practitioners should carefully consider the specific protocol, including joint  
153 angles, to ensure repeatability of the measures (27).

154 While adopting standardized knee and hip angles during the IMTP may seem logical, this  
155 practice may place athletes in a sub-optimal pulling position, due to the range of angles  
156 reported across individuals for the second pull phase of the clean (30, 31). Therefore, it is

157 best to consider the individual athletes' appropriate second pull position and then quantify the  
158 knee and hip angles. This practice allows for the individual athlete's anthropometrics to be  
159 considered and allows them to assume an optimal pulling position, in line with the range of  
160 joint angles recommended by Beckham et al. (8). Once the pulling position is established  
161 then it is recommended that practitioners and researchers ensure that the individual starting  
162 postures are replicated between trials and testing sessions. Joint angles should be assessed  
163 prior to the commencement of the pull due to slight changes in joint angles during the pull  
164 (8).

165 Haff et al. (32) suggest using minimal pre-tension prior to initiation of the pull, as this is  
166 likely to impact both time specified force and RFD, with Dos'Santos et al. (26) recently  
167 reporting that the 175° hip angle results in significantly higher 'body weight' due to increased  
168 pre-tension, compared to a 145° hip angle, which may have contributed to in the differences  
169 in time specific force values and RFD that were reported. Similarly, Maffiuletti et al. (43)  
170 suggested that pre-tension is undesirable when assessing isometric RFD, albeit with a focus  
171 on single joint assessment; it would, therefore, be advantageous to visually inspect the force-  
172 time data pre and post isometric pull, to ensure that there are no differences in force, which  
173 should represent body weight.

174 Interestingly, numerous authors state that they have adopted the postures previously reported  
175 by other researchers, but in fact report different angles to those stated in the studies that they  
176 cite, or cite multiple researchers who reported different postures (Table 5). These differing  
177 postures are most likely related to individual athlete anthropometric profiles. It is therefore  
178 important that researchers carefully report and justify their choice of joint angles, but more  
179 importantly, standardize these between trials and testing sessions.

180 Other researchers have used strain gauge based equipment, with the handle attached via a  
181 chain (16, 17, 37, 38, 48) with a range of sampling frequencies (100-133 Hz (17, 37, 38)) and  
182 joint angles (knee 120-130° (17), 142±4°(38), 143±7° (37), 160° (48); hip 139±4° (38),  
183 144±5° (37)). However, findings of two research groups that compared strain gauge systems  
184 to a force platform demonstrated that the strain gauge significantly underestimated PF, by  
185 ~8% (38) to ~10% (20). Additionally, James et al. (38) found that measures of RFD did not  
186 meet acceptable standards of reliability. While such systems can measure PF, which can be  
187 ratio or allometrically scaled, there does not seem to be an effective way to accurately  
188 measure or calculate RFD, and are therefore not recommended if practitioners have access to  
189 a force platform.

190

#### 191 **Recommendations for Correct IMTP Assessment**

192 Due to the noticeable variations in assessment procedures, including posture, sampling  
193 frequency, and methods of calculating specific variables (namely use of different sampling  
194 frequencies, onset thresholds, and the method for the calculation of RFD), we suggest  
195 appropriate standardization of all testing procedures for the IMTP. Such standardization  
196 should permit more meaningful comparisons of individual performances between testing  
197 sessions, comparisons between athletes and more effective comparisons between published  
198 studies. Standardization should also include the verbal cues as attentional focus has been  
199 shown to affect force production, with an external focus of ‘push as hard and fast as possible’  
200 resulting in greater PF compared to an internal focus (34).

201

202

## 203 **Recommended Testing Procedures**

204 Prior to initiation of IMTP testing, the bar height necessary to obtain the correct body  
205 position should be determined. This should be an iterative process in which the athlete starts  
206 with a bar height that allows the athlete to assume a body position that replicates the start of  
207 the second pull position during the clean. The bar height should then be adjusted up or down  
208 to allow the athlete to obtain the optimal knee (125-145°) and hip (140-150°) angles (6, 8,  
209 26). The body position should be very similar to the second pull of the clean and the clean  
210 grip mid-thigh pull exercise (19): upright torso, slight flexion in the knee resulting in some  
211 dorsiflexion, shoulder girdle retracted and depressed, shoulders above or slightly behind the  
212 vertical plane of the bar, feet roughly centered under the bar approximately hip width apart,  
213 knees underneath and in front of the bar, and thighs in contact with the bar (close to the  
214 inguinal crease dependent on limb lengths) (Figure 2). When making joint measurements, the  
215 athlete should ensure that no tension is applied to the bar but that all “slack” (e.g. elbow  
216 flexion, shoulder girdle elevation/protraction) is removed from the body, as this would result  
217 in a change in joint angles during the maximal effort which is undesirable (8).

218

219 [Insert figure 2 about here]

220

221 While the use of a “self-selected” body position is likely beneficial to efficiency of testing, it  
222 is not recommended without ensuring that the hip and knee joint angles fall within the ranges  
223 recommended above, due to the influence of body positioning on force generation (6, 8, 26).  
224 The bar height used and joint angles obtained should be recorded so that repeated  
225 measurements can be standardized and therefore replicate the individuals’ body position

226 between session, ensuring that differing results in subsequent testing are not the result of  
227 changed body position (8, 26). It is also considered best practice to measure the individuals  
228 grip width and foot position and standardize these for individuals across sessions (unless  
229 working with youth athletes where changes in stature as a result of maturation may require  
230 increased stance and grip width) as each can affect body positioning relative to the bar (19).  
231 After the bar height and posture have been established, a short familiarization session of  
232 submaximal trials is recommended approximately 48 hours prior to testing (e.g. 3 x 3 second  
233 trials, each of 50-, 75- and 90% of perceived maximum effort). While a consensus on the  
234 optimal amount of familiarization has not yet been reached, nearly all IMTP studies use some  
235 familiarization.

236 Athletes should complete some manner of standard generalized warm-up (62). While there is  
237 variability in the generalized warm-up chosen among studies, most studies use a warm-up  
238 that incorporates clean derivatives, such as the dynamic mid-thigh pull, and should thus be a  
239 component of the standard warm-up (7, 21, 24, 32, 33). Submaximal trials of the IMTP are  
240 also recommended prior to maximal effort trials (e.g. 3 seconds each of: 50% maximal effort,  
241 75% maximal effort, 90% maximal effort, separated by 60 seconds rest). During this time, the  
242 athlete should be secured to the bar using lifting straps and athletic tape to ensure that grip  
243 strength is not a limiting factor (Figure 3) (30, 33).

244

245 [Insert figure 3 about here]

246 For each of the maximal effort trials, standardized instructions should be given to the athlete  
247 of some iteration of “push your feet into the ground as fast and as hard as possible” to ensure  
248 that both maximal RFD and PF are obtained (10, 34). It is essential that athletes understand  
249 that the focus is to drive the feet directly into the force platform and not attempt to pull the

250 bar with the arms, or rise up on to their toes. The athlete should get into the correct body  
251 position for the IMTP, using just enough pre-tension to achieve the correct body position and  
252 remove “slack” from the body, but without any more pre-tension than is necessary to get the  
253 “quiet standing” necessary for a stable force baseline (43). This can be verified by monitoring  
254 the athlete’s body positioning and ensuring the force trace created by the athlete is both  
255 similar to body mass and steady, with trials where a change in force  $>50$  N occurs during this  
256 period rejected (21). This should be explained to the athletes and they should be encouraged  
257 to stay as still as possible during this period to accurately determine body weight and onset  
258 threshold. A countdown of “3, 2, 1, *PULL!*” gives the athlete sufficient warning to be ready  
259 to give a maximum effort and provides at least one second of quiet standing to enable the  
260 identification of the onset of the pull (Figure 5a). Strong verbal encouragement from  
261 researchers and teammates ensures that the athlete gives a maximum effort (9). A minimum  
262 of two trials should be collected, provided that each of those trials have no errors by the  
263 athlete (e.g. countermovement, excessive pre-tension, leaning on the bar prior to the pull  
264 (Figure 4). With increasing PF, additional trials should be performed, until the PF values of  
265 the trials are separated by  $<250$  N (30, 33). It is noted, however, that a percentage of peak  
266 force may be advantageous as an absolute value will affect stronger and weaker athletes  
267 differently, although the exact effect of this has not been investigated.

268

269 [Insert figure 4 about here]

270 Visual inspection of the force-time curves during testing can easily be used to determine if  
271 the trials are acceptable, or if additional trials should be performed. In addition to the trials  
272 being within 250 N between attempts, trials should be repeated if there is not a stable  
273 weighing period (clear fluctuation in the force-time data) or a clear countermovement prior to

274 the initiation of the pull (Figure 5c), as this will interfere with accurate identification of the  
275 initiation of the pull (19), or if the PF occurs at the end of the trial (Figure 5b). It is also  
276 important to check that the force during the initial period of quiet standing (in the ready  
277 position, strapped to the bar, immediately prior to commencing the pull) represents body  
278 weight, and therefore no prior tension has been applied (Figure 5a) as this will interfere with  
279 pull onset identification (19).

280

281 [Insert figure 5 about here]

282

### 283 **Recommended Data Analysis and Reporting**

284 Collection of IMTP force-time data can be compiled accurately with a sampling frequency as  
285 low as 500 Hz , but if higher sampling frequencies can be used then they are preferred as they  
286 may increase the accuracy of time dependent measures (21). Specifically, the utilization of  
287 frequencies  $\geq 1000$  Hz are recommended especially if early force-time variables are of interest  
288 (e.g. force at 50 or 100 ms) (21). There are not enough data for a consensus regarding  
289 optimal filtering and/or smoothing methods for the IMTP (23); although unfiltered data has  
290 been suggested as optimal for analysis of countermovement jump performance (61) and  
291 where possible, unfiltered data for isometric testing (23, 43). It is therefore suggested that  
292 unfiltered and non-smoothed data is used for subsequent analysis (23), as most of the RFD  
293 and impulse characteristics are dependent upon an accurate determination of the start of the  
294 pull (21), although data from portable force platforms may exhibit greater ‘noise’ and warrant  
295 smoothing. Accurate identification of the start of the inflection point is often achieved using  
296 automated methods - we recommend using 5 standard deviations of body weight during an



297 initial one second weighing period prior to the (usually one second) of quiet standing (in the  
298 ready position, strapped to the bar, immediately prior to commencing the pull) as the  
299 threshold for determining the onset of the pull (21), although this may vary with technical  
300 idiosyncrasies of different force platforms (e.g. noise magnitude). Trials that do not have a  
301 stable baseline force trace during the weighing period (change in force >50 N) should be  
302 rejected and subsequently another trial should be performed (21, 43) (Figure 5). To facilitate  
303 this stable period, it is essential to enforce and practice this during the warm-up /  
304 familiarization trials.

305 It is recommended that time-specific RFD epochs (50-, 100-, 150-, 200- and 250 ms  
306 commonly reported) should be used when using the IMTP as a sport performance diagnostic  
307 tool as these are not only reliable (32), but can be selected specific to the durations relevant to  
308 the specific sporting tasks, such as ground contact time during acceleration or peak running  
309 speeds. In contrast, maximal strength capabilities can be inferred from PF (Table 1).

310 When reporting results from IMTP testing, it is important that the hip and knee angles used  
311 by each athlete, to establish the bar height, be reported (8, 26). Such standardization of  
312 posture between trials and testing sessions ensures that data is comparable between sessions,  
313 groups of athletes and studies (8, 26). While there is no consensus as to the superiority of  
314 either net or gross force values for the IMTP, it is important that researchers report whether  
315 body weight was or was not included in the force and impulse values reported (7). Other  
316 methodological considerations, such as the method for identifying the onset of the pull (and  
317 threshold) (21), methods used for smoothing/filtering force platform data (23), sampling  
318 frequency and other aspects of analysis (22), such as the exponent used for allometric scaling,  
319 should be reported, as each are important for accurately interpreting results from the study.

320

321 **References**

- 322 1. Bailey CA, Sato K, Alexander R, Chiang CY, and Stone M. Isometric force  
323 production symmetry and jumping performance in collegiate athletes. *J Trainology* 2:  
324 1-5, 2013.
- 325 2. Bailey CA, Sato K, Burnett A, and Stone MH. Carry-over of force production  
326 symmetry in athletes of differing strength levels. *J Strength Cond Res.* 29: 3188-3196,  
327 2015.
- 328 3. Bailey CA, Sato K, Burnett A, and Stone MH. Force-production asymmetry in male  
329 and female athletes of differing strength levels. *Int J Sports Physiol Perform.* 10: 504-  
330 508, 2015.
- 331 4. Bartolomei S, Sadres E, Church DD, Arroyo E, Iii JAG, Varanoske AN, Wang R,  
332 Beyer KS, Oliveira LP, Stout JR, and Hoffman JR. Comparison of the recovery  
333 response from high-intensity and high-volume resistance exercise in trained men. *Eur*  
334 *J Appl Physiol* 117: 1287-1298, 2017.
- 335 5. Beattie K, Carson BP, Lyons M, and Kenny IC. The Effect of maximal- and  
336 explosive-strength training on performance indicators in cyclists. *Int J Sports Physiol*  
337 *Perform* 12: 470-480, 2017.
- 338 6. Beckham G, Lamont H, Sato K, Ramsey M, Haff GG, and Stone M. Isometric  
339 strength of powerlifters in key positions of the conventional deadlift. *J Trainology* 1,  
340 2012.
- 341 7. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey M, Lamont H, Hornsby G, Haff  
342 G, and Stone M. Relationships of isometric mid-thigh pull variables to weightlifting  
343 performance. *J Sports Med Phys Fitness* 53: 573-581, 2013.
- 344 8. Beckham GK, Sato K, Mizuguchi S, Haff GG, and Stone MH. Effect of body position  
345 on force production during the isometric mid-thigh pull. *J Strength Cond Res.* 32(1):  
346 48-56: 18.
- 347 9. Belkhiria C, De Marco G, and Driss T. Effects of verbal encouragement on force and  
348 electromyographic activations during exercise. *J Sports Med Phys Fitness* 58: 750-  
349 757, 2018.
- 350 10. Bemben MG, Clasey JL, and Massey BH. The effect of the rate of muscle contraction  
351 on the force-time curve parameters of male and female subjects. *Res Q Exerc Sport*  
352 61: 96-99, 1990.
- 353 11. Comfort P, Jones PA, McMahon JJ, and Newton R. Effect of knee and trunk angle on  
354 kinetic variables during the isometric midthigh pull: test-retest reliability. *Int J Sports*  
355 *Physiol Perform* 10: 58-63, 2015.
- 356 12. Comfort P and McMahon JJ. Reliability of maximal back squat and power clean  
357 performances in inexperienced athletes. *J Strength Cond Res.* 29: 3089-3096, 2015.
- 358 13. Comfort P and Pearson SJ. Scaling--which methods best predict performance? *J*  
359 *Strength Cond Res* 28: 1565-1572, 2014.
- 360 14. Comfort P, Thomas C, Dos'Santos T, Jones PA, Suchomel TJ, and McMahon JJ.  
361 Comparison of methods of calculating dynamic strength index. *Int J Sports Physiol*  
362 *Perform:* 1-20, 2017.
- 363 15. Cormie P, McGuigan MR, and Newton RU. Developing maximal neuromuscular  
364 power: Part 1--biological basis of maximal power production. *Sports Med* 41: 17-38,  
365 2011.
- 366 16. Crewther BT, Carruthers J, Kilduff LP, Sanctuary CE, and Cook CJ. Temporal  
367 associations between individual changes in hormones, training motivation and  
368 physical performance in elite and non-elite trained men. *Biol Sport* 33: 215-221, 2016.

- 369 17. Davis GR, Gallien GJ, Moody KM, LeBlanc NR, Smoak PR, and Bellar D. Cognitive  
370 function and salivary DHEA levels in physically active elderly african american  
371 women. *Int J Endocrinol* 2015: 6, 2015.
- 372 18. De Witt JK, English KL, Crowell JB, Kalogera KL, Guilliams ME, Nieschwitz BE,  
373 Hanson AM, and Ploutz-Snyder LL. Isometric mid-thigh pull reliability and  
374 relationship to deadlift 1RM. *J Strength Cond Res.* 32 (2): 528-533. 2018.
- 375 19. DeWeese BH, Serrano AJ, Scruggs SK, and Burton JD. The midhigh pull: proper  
376 application and progressions of a Weightlifting movement derivative. *Strength Cond J*  
377 35: 54-58, 2013.
- 378 20. Dobbin N, Hunwicks R, Jones B, Till K, Highton J, and Twist C. Criterion and  
379 construct validity of an isometric mid-thigh pull dynamometer for assessing whole  
380 body strength in professional rugby league players. *Int J Sports Physiol Perform.*  
381 13(2): 235-239. 2018.
- 382 21. Dos'Santos T, Jones PA, Comfort P, and Thomas C. Effect of different onset  
383 thresholds on isometric mid-thigh pull force-time variables. *J Strength Cond Res* 31:  
384 3467-3473, 2017.
- 385 22. Dos'Santos T, Jones PA, Kelly J, McMahon JJ, Comfort P, and Thomas C. Effect of  
386 sampling frequency on isometric midhigh-pull kinetics. *Int J Sports Physiol Perform*  
387 11: 255-260, 2016.
- 388 23. Dos'Santos T, Lake JP, Jones PA, and Comfort P. Effect of low pass filtering on  
389 isometric mid-thigh pull kinetics. *J Strength Cond Res.* 32: 983-989, 2018.
- 390 24. Dos'Santos T, Thomas C, Comfort P, McMahon JJ, Jones PA, Oakley NP, and Young  
391 AL. Between-session reliability of isometric mid-thigh pull kinetics and maximal  
392 power clean performance in male youth soccer players. *J Strength Cond Res*  
393 Published ahead of print, 2017.
- 394 25. Dos'Santos T, Thomas C, Jones PA, and Comfort P. Assessing muscle strength  
395 asymmetry via a unilateral stance isometric mid-thigh pull. *Int J Sports Physiol*  
396 *Perform.* 12(4): 505-511. 2017.
- 397 26. Dos'Santos T, Thomas C, Jones PA, McMahon JJ, and Comfort P. The effect of hip  
398 joint angle on isometric mid-thigh pull kinetics. *J Strength Cond Res.* 31(10):2748-  
399 2757. 2017 .
- 400 27. Drake D, Kennedy R, and Wallace E. The validity and responsiveness of isometric  
401 lower body multi-joint tests of muscular strength: a systematic review. *Sports Med*  
402 *Open* 3: 23, 2017.
- 403 28. Faigenbaum AD, McFarland JE, Herman RE, Naclerio F, Ratamess NA, Kang J, and  
404 Myer GD. Reliability of the one-repetition-maximum power clean test in adolescent  
405 athletes. *J Strength Cond Res* 26: 432-437, 2012.
- 406 29. Gescheit DT, Cormack SJ, Reid M, and Duffield R. Consecutive days of prolonged  
407 tennis match play: performance, physical, and perceptual responses in trained players.  
408 *Int J Sports Physiol Perform.* 10: 913-920, 2015.
- 409 30. Haff GG, Carlock JM, Hartman MJ, Kilgore JL, Kawamori N, Jackson JR, Morris  
410 RT, Sands WA, and Stone MH. Force-time curve characteristics of dynamic and  
411 isometric muscle actions of elite women olympic weightlifters. *J Strength Cond Res*  
412 19: 741-748, 2005.
- 413 31. Haff GG, Jackson JR, Kawamori N, Carlock JM, Hartman MJ, Kilgore JL, Morris  
414 RT, Ramsey MW, Sands WA, and Stone MH. Force-time curve characteristics and  
415 hormonal alterations during an eleven-week training period in elite women  
416 weightlifters. *J Strength Cond Res* 22: 433-446, 2008.

- 417 32. Haff GG, Ruben RP, Lider J, Twine C, and Cormie P. A comparison of methods for  
418 determining the rate of force development during isometric mid-thigh clean pulls. *J*  
419 *Strength Cond Res* 29: 386-395, 2015.
- 420 33. Haff GG, Stone M, O'Bryant HS, Harman E, Dinan C, Johnson R, and Han K-H.  
421 Force-time dependent characteristics of dynamic and isometric muscle actions. *J*  
422 *Strength Cond Res*. 11: 269-272, 1997.
- 423 34. Halperin I, Williams KJ, Martin DT, and Chapman DW. The effects of attentional  
424 focusing instructions on force production during the isometric midthigh pull. *J*  
425 *Strength Cond Res*. 30: 919-923, 2016.
- 426 35. Helms ER, Zinn C, Rowlands DS, Naidoo R, and Cronin J. High-protein, low-fat,  
427 short-term diet results in less stress and fatigue than moderate-protein, moderate-fat  
428 diet during weight loss in male Weightlifters: A pilot study. *Int J Sport Nutr Exerc*  
429 *Metab*. 25: 163-170, 2015.
- 430 36. Hornsby W, Gentles J, MacDonald C, Mizuguchi S, Ramsey M, and Stone M.  
431 Maximum strength, rate of force development, jump height, and peak power  
432 alterations in Weightlifters across five months of training. *Sports* 5: 78, 2017.
- 433 37. James LP, Beckman EM, Kelly VG, and Haff GG. The neuromuscular qualities of  
434 higher and lower-level mixed martial arts competitors. *Int J Sports Physiol Perform*.  
435 12(5): 612-620. 2017.
- 436 38. James LP, Roberts LA, Haff GG, Kelly VG, and Beckman EM. Validity and  
437 reliability of a portable isometric mid-thigh clean pull. *J Strength Cond Res* 31: 1378-  
438 1386, 2017.
- 439 39. Kawamori N, Rossi SJ, Justice BD, Haff EE, Pistilli EE, O'Bryant HS, Stone MH, and  
440 Haff GG. Peak force and rate of force development during isometric and dynamic  
441 mid-thigh clean pulls performed at various intensities. *J Strength Cond Res*. 20: 483-  
442 491, 2006.
- 443 40. Khamoui AV, Brown LE, Nguyen D, Uribe BP, Coburn JW, Noffal GJ, and Tran T.  
444 Relationship between force-time and velocity-time characteristics of dynamic and  
445 isometric muscle actions. *J Strength Cond Res* 25: 198-204, 2011.
- 446 41. Kraska JM, Ramsey MW, Haff GG, Fethke N, Sands WA, Stone ME, and Stone MH.  
447 Relationship between strength characteristics and unweighted and weighted vertical  
448 jump height. *Int J Sports Physiol Perform*. 4: 461-473, 2009.
- 449 42. Leary BK, Statler J, Hopkins B, Fitzwater R, Kesling T, Lyon J, Phillips B, Bryner  
450 RW, Cormie P, and Haff GG. The relationship between isometric force-time curve  
451 characteristics and club head speed in recreational golfers. *J Strength Cond Res* 26:  
452 2685-2697, 2012.
- 453 43. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, and Duchateau J. Rate  
454 of force development: physiological and methodological considerations. *Eur J Appl*  
455 *Physiol* 116: 1091-1116, 2016.
- 456 44. Mangine GT, Hoffman JR, Wang R, Gonzalez AM, Townsend JR, Wells AJ, Jajtner  
457 AR, Beyer KS, Boone CH, Miramonti AA, LaMonica MB, Fukuda DH, Ratamess  
458 NA, and Stout JR. Resistance training intensity and volume affect changes in rate of  
459 force development in resistance-trained men. *Eur J Applied Physiol*. 116: 2367-2374,  
460 2016.
- 461 45. McGuigan M and Winchester JB. The relationship between isometric and dynamic  
462 strength in collegiate football players. *J Sports Sci Med* 7: 101-105, 2008.
- 463 46. McGuigan MR, Newton MJ, Winchester JB, and Nelson AG. Relationship between  
464 isometric and dynamic strength in recreationally trained men. *J Strength Cond Res* 24:  
465 2570-2573, 2010.



- 466 47. McGuigan MR, Winchester JB, and Erickson T. The importance of isometric  
467 maximum strength In college wrestlers. *J Sports Sci Med*. 5: 108-113, 2006.
- 468 48. Moran J, Sandercock GRH, Ramírez-Campillo R, Wooller J-J, Logothetis S,  
469 Schoenmakers PPJM, and Parry DA. Maturation-related differences in adaptations to  
470 resistance training in young male swimmers. *J Strength Cond Res*. 32(1): 139-149.  
471 2018.
- 472 49. Nuzzo JL, McBride JM, Cormie P, and McCaulley GO. Relationship between  
473 countermovement jump performance and multijoint isometric and dynamic tests of  
474 strength. *J Strength Cond Res* 22: 699-707, 2008.
- 475 50. Oranchuk DJ, Robinson TL, Switaj ZJ, and Drinkwater EJ. Comparison of the hang  
476 high-pull and loaded jump squat for the development of vertical jump and isometric  
477 force-time characteristics. *J Strength Cond Res*. Publish Ahead of Print, 2017.
- 478 51. Painter KB, Haff GG, Ramsey MW, McBride J, Triplett T, Sands WA, Lamont HS,  
479 Stone ME, and Stone MH. Strength gains: block versus daily undulating periodization  
480 weight training among track and field athletes. *Int J Sports Physiol Perform* 7: 161-  
481 169, 2012.
- 482 52. Secomb JL, Farley OR, Lundgren L, Tran T, King A, Nimphius S, and Sheppard J.  
483 Associations between the performance of scoring manouvres and lower-body strength  
484 and power in elite surfers. *Int J Sports Sci Coach* 10: 911-918, 2015.
- 485 53. Secomb JL, Lundgren LE, Farley OR, Tran TT, Nimphius S, and Sheppard JM.  
486 Relationships between lower-body muscle structure and lower-body strength, power,  
487 and muscle-tendon complex stiffness. *J Strength Cond Res* 29: 2221-2228, 2015.
- 488 54. Secomb JL, Nimphius S, Farley OR, Lundgren L, Tran T, and Sheppard J.  
489 Relationships between lower-body muscle structure and, lower-body strength,  
490 explosiveness and eccentric leg stiffness in adolescent athletes. *J Sports Sci Med* 14:  
491 691-697, 2015.
- 492 55. Seitz LB, Reyes A, Tran TT, de Villarreal ES, and Haff GG. Increases in lower-body  
493 strength transfer positively to sprint performance: a systematic review with meta-  
494 analysis. *Sports Med* 44 1693-1702, 2014.
- 495 56. Sheppard J, Chapman D, and Taylor K. An evaluation of a strength qualities  
496 assessment method for the lower body. *JASC* 19: 4-10, 2011.
- 497 57. Sjokvist J, Sandbakk O, Willis SJ, Andersson E, and Holmberg HC. The effect of  
498 incline on sprint and bounding performance in cross-country skiers. *J Sports Med*  
499 *Phys Fitness* 55: 405-414, 2015.
- 500 58. Spiteri T, Newton RU, and Nimphius S. Neuromuscular strategies contributing to  
501 faster multidirectional agility performance. *J Electromyogr Kinesiol* 25: 629-636,  
502 2015.
- 503 59. Spiteri T, Nimphius S, Hart NH, Specos C, Sheppard JM, and Newton RU.  
504 Contribution of strength characteristics to change of direction and agility performance  
505 in female basketball athletes. *J Strength Cond Res* 28: 2415-2423, 2014.
- 506 60. Stone MH, Sands WA, Carlock J, Callan S, Dickie D, Daigle K, Cotton J, Smith SL,  
507 and Hartman M. The importance of isometric maximum strength and peak rate-of-  
508 force development in sprint cycling. *J Strength Cond Res* 18: 878-884, 2004.
- 509 61. Street G, McMillan S, Board W, Rasmussen M, and Heneghan JM. Sources of error  
510 in determining countermovement jump height with the impulse method. *J Appl*  
511 *Biomech* 17: 43-54, 2001.
- 512 62. Suchomel TJ, Lamont HS, and Moir GL. Understanding vertical jump potentiation: a  
513 deterministic model. *Sports Med* 46: 809-828, 2016.
- 514 63. Suchomel TJ, Nimphius S, and Stone MH. The importance of muscular strength in  
515 athletic performance. *Sports Med* 46: 1419-1449, 2016.

- 516 64. Thomas C, Comfort P, Chiang CY, and Jones PA. Relationship between isometric  
517 mid-thigh pull variables and sprint and change of direction performance in collegiate  
518 athletes. *J Trainology* 4: 6-10, 2015.
- 519 65. Thomas C, Dos'Santos T, Comfort P, and Jones P. Between-session reliability of  
520 common strength- and power-related measures in adolescent athletes. *Sports* 5: 15,  
521 2017.
- 522 66. Thomas C, Jones PA, and Comfort P. Reliability of the dynamic strength index in  
523 collegiate athletes. *Int J Sports Physiol Perform* 10: 542-545, 2015.
- 524 67. Thomas C, Jones PA, Rothwell J, Chiang CY, and Comfort P. An Investigation into  
525 the relationship between maximum isometric strength and vertical jump performance.  
526 *J Strength Cond Res* 29: 2176-2185, 2015.
- 527 68. Tran TT, Lundgren L, Secomb J, Farley ORL, Haff GG, Seitz LB, Newton RU,  
528 Nimphius S, and Sheppard JM. Comparison of physical capacities between  
529 nonselected and selected elite male competitive surfers for the national junior team.  
530 *Int J Sports Physiol Perform* 10: 178-182, 2015.
- 531 69. Wang R, Hoffman JR, Tanigawa S, Miramonti AA, La Monica MB, Beyer KS,  
532 Church DD, Fukuda DH, and Stout JR. Isometric mid-thigh pull correlates with  
533 strength, sprint, and agility performance in collegiate rugby union players. *J Strength*  
534 *Cond Res* 30: 3051-3056, 2016.
- 535 70. Welch N, Moran K, Antony J, Richter C, Marshall B, Coyle J, Falvey E, and  
536 Franklyn-Miller A. The effects of a free-weight-based resistance training intervention  
537 on pain, squat biomechanics and MRI-defined lumbar fat infiltration and functional  
538 cross-sectional area in those with chronic low back. *BMJ Open Sport Exerc Med* 1,  
539 2015.
- 540 71. West DJ, Owen NJ, Jones MR, Bracken RM, Cook CJ, Cunningham DJ, Shearer DA,  
541 Finn CV, Newton RU, Crewther BT, and Kilduff LP. Relationships between force-  
542 time characteristics of the isometric midhigh pull and dynamic performance in  
543 professional rugby league players. *J Strength Cond Res* 25: 3070-3075, 2011.
- 544 72. Whittington J, Schoen E, Labounty LL, Hamdy R, Ramsey MW, Stone ME, Sands  
545 WA, Haff GG, and Stone MH. Bone mineral density and content of collegiate  
546 throwers: influence of maximum strength. *J Sports Med Phys Fitness* 49: 464-473,  
547 2009.
- 548 73. Winchester J, McGuigan MR, Nelson AG, and Newton M. The relationship between  
549 isometric and dynamic strength in college aged males. *J Strength Cond Res* 24: 1,  
550 2010.
- 551 74. Winchester JB, McBride JM, Maher MA, Mikat RP, Allen BK, Kline DE, and  
552 McGuigan MR. Eight weeks of ballistic exercise improves power independently of  
553 changes in strength and muscle fiber type expression. *J Strength Cond Res* 22: 1728-  
554 1734, 2008.

555

### 556 **Figure and Table Legends:**

557

558 Figure 1: Relationships between isometric mid-thigh pull peak force and performance in  
559 other tasks

560

561 Figure 2: Correct posture for the isometric mid-thigh pull, illustrating an upright trunk,  
562 replicating the start position of the second pull of the clean

563

564 Figure 3: Standardized warm-up procedure

565  
566 Figure 4: Standardized isometric mid-thigh pull testing procedure  
567  
568 Figure 5: Examples of acceptable and unacceptable isometric mid-thigh pull force-time traces  
569  
570  
571 Table 1: Relationships between peak force and performance in other activities  
572  
573 Table 2: Relationships between time specific force and performance in other activities  
574  
575 Table 3: Relationships between rate of force development and performance in other activities  
576  
577 Table 4: Relationships between time specific impulse and performance in other activities  
578  
579 Table 5: Reported testing and data analysis procedures

ACCEPTED

**Table 1: Relationships between peak force and performance in other activities**

Author(s)	Subjects	1RM	Sprint	Jump	Change of Direction	Other
Haff et al. (39)	8 trained (>2 years) men 1RM PC = 1.21 kg.kg <sup>-1</sup>			SJ PF: r = 0.76		Force during dynamic MTP 90% 1RM: r = 0.77 100% 1RM: r = 0.80
Stone et al. 60	30 competitive sprint cyclists			CMJ height: r = 0.59 CMJ PP: r = 0.79 SJ height: r = 0.51 SJ PP: r = 0.78		Absolute PF & Sprint cycling performances: r = 0.49-0.55 Relative PF & Sprint cycling performances: r = 0.45-0.60 AS PF & Sprint cycling performances: r = 0.45-0.58
Haff et al. (30)	6 elite women weightlifters	Snatch: r = 0.93		CMJ PP: r = 0.88 SJ PP: r = 0.92		
Kawamori et al. (39)	8 male collegiate weightlifters 1RM PC = 1.39 kg.kg <sup>-1</sup>			CMJ PF: r = 0.87 CMJ PRFD: r = 0.85 CMJ PP: r = 0.95 CMJ height: r = 0.82 SJ height: r = 0.87		Force during dynamic MTP 90% 1RM: r = 0.82
McGuigan et al. (47)	8 division III collegiate wrestlers	PC: r = 0.97 Squat: r = 0.96 BP: r = 0.73				
McGuigan & Winchester (45)	22 college football players 1RM PC = 1.11 kg.kg <sup>-1</sup> 1RM Squat = 1.75 kg.kg <sup>-1</sup>	PC, Squat, BP: r = 0.61-0.72*				
Nuzzo et al. (49)	12 division I collegiate athletes 1RM PC = 1.28 kg.kg <sup>-1</sup> 1RM Squat = 1.91 kg.kg <sup>-1</sup>	PC: r = 0.74		CMJ PP: r = 0.75 Relative PF & CMJ height: r = 0.59		
Kraska et al. (41)	41 female and 22 male collegiate athletes			SJ: r = 0.40 SJ20: r = 0.55 CMJ: r = 0.36 CMJ20: r = 0.55 AS PF:		



				SJ: r = 0.47 SJ20: r = 0.52 CMJ: r = 0.41 CMJ20: r = 0.52		
Whittington et al. (72)	7 NCAA Division I track and field athletes					Ball throw distance PF: r = 0.89 AS PF: r = 0.91
McGuigan et al. (46)	26 recreationally trained men 1RM Squat = 1.30 kg•kg <sup>-1</sup>	Squat: r = 0.97 BP: r = 0.99		CMJ height: r = 0.72		
Khamoui et al. (40)	19 recreationally trained men			Relative PF & CMJ height: r = 0.61		Relative PF & high pull PV: r = -0.60
West et al. (71)	39 professional rugby league players		Relative PF & 10 m sprint time: r = 0.37	Relative PF & CMJ height: r = 0.45		
Spiteri et al. (59)	12 competitive female basketball players	IMTP relative PF, back squat: r = 0.81			T-Test: r = -0.85 505 COD = -0.79	
Winchester et al. (73)	26 recreationally trained men 1RM Squat = 1.30 kg•kg <sup>-1</sup>	Squat: r = 0.97 BP: r = 0.99		CMJ height: r = 0.72		
Secomb et al. (53)	15 elite surfers			CMJ height: r = 0.65 SJ height: r = 0.58		
Beckham et al. (7)	12 collegiate-national level weightlifters	Snatch: r = 0.83 Clean & Jerk: r = 0.84 Total: r = 0.84				
Thomas et al. (64)	14 collegiate team sport athletes		5 m: r = -0.57 20 m: r = -0.69		505mod: r = -0.57	
Thomas et al. (67)	22 collegiate team sport athletes			CMJ PF: r = 0.45		
Wang et al. (69)	15 collegiate rugby players	Squat: r = 0.866				
PC = Power Clean; BP = Bench Press; SJ = Squat Jump; CMJ = Countermovement Jump; 505mod = Modified 505 change of direction PF = Peak Force; PP = Peak Power; PV = Peak Velocity; PRFD = Peak Rate of Force Development; AS = Allometrically Scaled *Individual correlations not reported						

**Table 2: Relationships between time specific force and performance in other activities**

Author(s)	Subjects	1RM	Sprint	Jump	Other
Kraska et al. (41)	41 female and 22 male collegiate athletes			PF50 SJ: $r = 0.33$ SJ20: $r = 0.52$ CMJ: $r = 0.27$ CMJ20: $r = 0.50$ AS PF50: SJ: $r = 0.33$ SJ20: $r = 0.48$ CMJ20: $r = 0.45$ PF90 SJ20: $r = 0.37$ CMJ20: $r = 0.33$ AS PF90: CMJ20: $r = 0.48$ PF250 SJ: $r = 0.39$ SJ20: $r = 0.56$ CMJ: $r = 0.34$ CMJ20: $r = 0.54$ AS PF250 SJ: $r = 0.42$ SJ20: $r = 0.51$ CMJ: $r = 0.34$ CMJ20: $r = 0.48$	
Beckham et al. (7)	12 collegiate-national level weightlifters	F100 Snatch: $r = 0.65$ Clean & Jerk: $r = 0.64$ Combined Total: $r = 0.65$ F150 Snatch: $r = 0.64$ Clean & Jerk: $r = 0.61$ Combined Total: $r = 0.62$ F200 Snatch: $r = 0.73$ Clean & Jerk: $r = 0.71$			

		Combined Total: $r = 0.72$ F250 Snatch: $r = 0.80$ Clean & Jerk: $r = 0.80$ Combined Total: $r = 0.80$			
West et al. (71)	39 professional rugby league players		F100 & 10 m: $r = -0.66$ Relative F100 & 10 m: $r = -0.68$	F100 & CMJ PP: $r = 0.55$ Relative F100 & CMJ PP: $r = 0.38$ Relative F100 & CMJ height: $r = 0.43$	
Wang et al. (69)	15 collegiate rugby players	Squat F90: $r = 0.76$ F100: $r = 0.78$ F150: $r = 0.78$ F200: $r = 0.77$ F250: $r = 0.82$			
Leary et al. (42)	12 recreational golfers				<i>Golf Club Head Speed</i> ASF150 & Mean Club Head Speed: $r = 0.46$ ASF150 & Max' Club Head Speed: $r = 0.47$
F90 = Force at 90 ms; F100 = Force at 100 ms; F150 = Force at 150 ms; F200 = Force at 200 ms; F250 = Force at 250 ms AS = Allometrically Scaled; SJ20 = Squat Jump with 20 kg; CMJ20 = Countermovement Jump with 20 kg					

**Table 3: Relationships between RFD and performance in other activities**

Author(s)	Subjects	1RM	Sprint	Jump	Change of Direction	Other
Haff et al. (33)	8 trained (>2 years) men 1RM PC = 1.21 kg•kg <sup>-1</sup>			PRFD SJ Power: r = 0.76 SJ Height: r = 0.82		RFD during dynamic MTP 80% 1RM: r = 0.84 90% 1RM: r = 0.88 100% 1RM: r = 0.84
Haff et al. (30)	6 elite women weightlifters	PRFD Snatch: r = 0.79 Combined Total: r = 0.80		PRFD CMJ PP: r = 0.81 SJ PP: r = 0.84		
McGuigan et al. (47)	8 division III collegiate wrestlers					PRFD & Coaching Ranking: r = 0.62
Kawamori et al. (39)	8 male collegiate weightlifters 1RM PC = 1.39 kg•kg <sup>-1</sup>					Force during dynamic MTP 90% 1RM: r = 0.69 120% 1RM: r = 0.74
Nuzzo et al. (49)	12 division I collegiate athletes 1RM PC = 1.28 kg•kg <sup>-1</sup> 1RM Squat = 1.91 kg•kg <sup>-1</sup>			PRFD CMJ PP: r = 0.65		
Kraska et al. (41)	41 female and 22 male collegiate athletes			PRFD SJ: r = 0.48 SJ20: r = 0.66 CMJ: r = 0.43 CMJ20: r = 0.62		
Whittington et al. (72)	7 NCAA Division I track and field athletes					Ball throw distance: r = 0.78
Khamoui et al. (40)	19 recreationally trained men					RFD50 & high pull PV: r = 0.56 RFD100 & high pull PV: r = 0.56
West et al. (71)	39 professional rugby league		PRFD 10 m: r = -0.66	PRFD CMJ height: r =		

	players			0.39		
Beckham et al. (7)	12 collegiate-national level weightlifters	RFD200 Snatch: r = 0.65 Combined Total: r = 0.60 RFD250 Snatch: r = 0.78 Clean & Jerk: r = 0.72 Combined Total: r = 0.75				
Thomas et al. (64)	14 collegiate team sport athletes		PRFD 5 m: r = -0.58 20 m: r = 0.71		PRFD 505mod: r = -0.57	
Wang et al. (69)	15 collegiate rugby players		5 m: PRFD: r = -0.54 RFD30: r = 0.57 RFD50: r = 0.53		Pro agility: PRFD: r = -0.52 RFD30: r = 0.52 RFD50: r = 0.53 RFD90: r = 0.53 RFD100: r = 0.52	
PRFD = Peak RFD; RFD30 = Mean RFD between 0-30 ms; RFD50 = Mean RFD between 0-50 ms; RFD90 = Mean RFD between 0-90 ms RFD100 = Mean RFD between 0-100 ms; RFD200 = Mean RFD between 0-200 ms; RFD250 = Mean RFD between 0-250 ms; PV = Peak Velocity						

**Table 4: Relationships between time specific impulse and performance in other activities**

Author(s)	Subjects	Sprint	Jump	Change of Direction
Thomas et al. (64)	14 collegiate team sport athletes	Imp100 5 m: $r = -0.71$ 20 m: $r = 0.75$ Imp300 5 m: $r = -0.74$ 20 m: $r = 0.78$		Imp100, 505mod: $r = -0.58$ Imp300, 505mod: $r = -0.62$
Thomas et al. (67)	22 collegiate team sport athletes		Imp100 SJ PF: $r = 0.57$ SJ PP: $r = 0.60$ CMJ PF: $r = 0.64$ CMJ PP: $r = 0.51$ Imp200 SJ PF: $r = 0.56$ SJ PP: $r = 0.59$ CMJ PF: $r = 0.63$ CMJ PP: $r = 0.50$ Imp300 SJ PF: $r = 0.58$ SJ PP: $r = 0.60$ CMJ PF: $r = 0.63$ CMJ PP: $r = 0.49$	
Imp100 = Impulse over 100 ms; Imp200 = Impulse over 200 ms; Imp300 = Impulse over 300 ms SJ = Squat Jump; CMJ = Countermovement Jump; PF = Peak Force; PP = Peak Power				

**Table 5: Reported Testing and Data Analysis Procedures**

Author(s)	Knee Angle	Hip Angle	Sampling Frequency	Onset Threshold	Scaling	Smoothing & Filtering	RFD Calculation
Haff et al. (33)	144 ± 5°	145 ± 3°	500 Hz	---	Net Force	---	PRFD (2 ms window)
Stone et al. (60)	140-145°	---	600 Hz	---	Net Absolute, Relative and AS	---	PRFD (1.7 ms window)
Haff et al. (30)	127-145° *	---	600 Hz	---	Net Force	---	PRFD (1.7 ms window)
McGuigan et al. (47)	130°	---	500 Hz	---	Absolute	---	PRFD (2 ms window)
Kawamori et al. (39)	141±10°	124±11°	500 Hz	---	---	---	PRFD (2 ms window)
Haff et al. (31)	127-145° *	---	600 Hz	---	Net Force	---	PRFD (1.7 ms window)
Nuzzo et al. (49)	140°	---	1000 Hz	---	Ratio	---	Mean RFD
Winchester et al. (74)	130°	---	---	---	Net	---	---
Winchester et al. (73) #	---	---	---	---	---	---	---
McGuigan & Winchester (45)	130°	---	960 Hz	---	---	---	--- Assumed peak due to the values
Kraska et al. (41)	120-135°	170-175° ¥ In line with Haff et al (1997)	1000 Hz	---	Absolute & AS	---	--- Assumed peak due to the values
Whittington et al. (72)	120-135° 'Self-selected'	170-175° 'Self-selected'	1000 Hz	---	---	---	PRFD (1 ms window)
McGuigan et al. (46)	130°	---	960 Hz	---	--- Assumed	---	--- Assumed mean

					Net due to the values		due to the values
West et al. (71)	120-130° ¥ In line with Haff et al (2005), Stone et al (2004)	---	1000 Hz	5SD of mean force after trigger	Net	Dual pass Butterworth filter (low pass, 20 Hz cut-off)	PRFD (1 ms window)
Crewther et al. (16)	120-130° ¥ In line with Haff et al (2005), Stone et al (2004)	---	1000 Hz	---	Net	Dual pass Butterworth filter (low pass, 20 Hz cut-off)	PRFD (1 ms window)
Beckham et al. (6)	¥ In line with Haff et al. (1997) and Kraska et al. (2009)	¥ In line with Haff et al. (1997) and Kraska et al. (2009)	1000 Hz	---	Absolute & AS	4 <sup>th</sup> Order Butterworth low pass filter 100 Hz	Not included
Beckham et al. (7)	120-135°	175°	1000 Hz	---	Absolute, Ratio & AS	4 <sup>th</sup> Order Butterworth low pass filter 100 Hz	Mean & PRFD (1 ms window)
Sheppard et al. (56)	130°	155-165°	600 Hz	---	Net	---	Not included
Comfort et al. (11)	120°, 130°, 140°, 150° & Self-selected (133 ± 3°)	125°, 145° & Self-selected (138 ± 4°)	600 Hz	40 N	Absolute	---	PRFD (1.7 ms window)
Thomas et al. (64)	Self-selected	Self-selected	600 Hz	---	Absolute	4 <sup>th</sup> Order Butterworth low pass filter 16 Hz	PRFD (1.7 ms window)
Thomas et al. (67)	Self-selected	Self-selected	600 Hz	---	Absolute & Relative	4 <sup>th</sup> Order Butterworth low pass filter 16 Hz	PRFD (1.7 ms window)



Thomas et al. (66)	Self-selected	Self-selected	600 Hz	---	Absolute	4 <sup>th</sup> Order Butterworth low pass filter 16 Hz	Not included
Haff et al. (32)	140.0 ± 6.6°	137.6 ± 12.9°	1000 Hz	---	Net	Rectangular smoothing with a moving half-width of 12	PRFD (20 ms window) RFD <sub>30, 50, 90, 100, 150, 200, 250</sub>
Secomb, et al. (52)	125-140°	---	600 Hz	---	Absolute and Relative	---	Not included
Secomb et al. (53)	125-140°	---	600 Hz	---	Absolute and Relative	---	Not included
Secomb et al. (54)	--- Stated similar to Haff et al. (2005)	--- Stated similar to Haff et al. (2005)	600 Hz	---	Absolute and Relative	---	Not included
Tran et al. (68)	--- Stated similar to Haff et al. (1997)	--- Stated similar to Haff et al. (1997)	600 Hz	---	Absolute and Relative (Assumed Net due to the values)	4 <sup>th</sup> Order Butterworth low pass filter 10 Hz	
Spiteri et al. (58)	140°	140°	2000 Hz	---	Relative	---	RFD <sub>30, 50, 90, 100</sub>
Sjokvist et al. (57)	--- States in line with Stone et al. (2004)				Absolute and Relative	---	Not included
Welch et al. (70)	No specific detail provided other than bar positioned at mid-thigh				Relative	---	Not included
Wang et al. (69)	Self-selected	Self-selected	1000 Hz	---	Net	---	PRFD (20 ms window) RFD <sub>30, 50, 90, 100, 150, 200, 250</sub>
Mangine et al.	Self-selected	Self-selected	1000 Hz	---	Net	---	PRFD (20 ms)

(44)							window) RFD <sub>30, 50, 90, 100,</sub> 150, 200, 250
Halperin et al. (34)	130-140°	Not stated	1000 Hz	---	---	---	Not included
Dos'Santos et al. (22)	Self-selected	Self-selected	2000 Hz (down-sampled to 1500, 1000 & 500 Hz)	75 N	Absolute	20 ms moving average	RFD <sub>100</sub> RFD <sub>150</sub> RFD <sub>200</sub>
Bartolomei et al. (4)	140°	125°	1000 Hz	---	Absolute	---	PRFD (20 ms window)
James et al. (38)	141.9 ± 4.3°	139.2 ± 4.1°	1000 Hz down sampled to 100 Hz to compare to strain gauge	20 N	Net	4 <sup>th</sup> Order Butterworth low pass filter 10 Hz	PRFD (20 ms window) RFD <sub>30, 50, 90, 100,</sub> 150, 200, 250
De Witt et al. (18)	144 ± 3°	137 ± 3°	1000 Hz	---	--- Assumed Net due to the values	---	PRFD (20 ms window) RFD <sub>30, 50, 90, 100,</sub> 150, 200, 250
Dos'Santos, Thomas et al. (24)	137-146° †	140-149° †	1000 Hz	40 N	Absolute	---	Not included
Dos'Santos, et al. (21)	Self-selected	Self-selected	1000 Hz	2.5% BW, 5% BW, 10% BW, >75 N, <b>5 SD BW</b>	Absolute	---	RFD <sub>100</sub> RFD <sub>150</sub> RFD <sub>200</sub>
Beckham et al. (8)	125°	125° & 145°	1000 Hz	---	Absolute & AS	2 <sup>nd</sup> Order Butterworth low pass filter 10 Hz	Not included
Oranchuk et al. (50)	135-145°	---	1000 Hz	2.5% of mean body mass, based on force-time data	Relative	4 <sup>th</sup> Order Butterworth filter, with 20 Hz cut-off	PRFD (20 ms window)

Dobbin et al. (20)	140°	Self-selected, shoulder above the bar (as described by Thomas et al., 2015)	1200 Hz	---	Net relative and AS	---	Not included
Beattie et al. (5)	131 ± 9°	---	1000 Hz	---	Relative	---	Not included
Dos'Santos et al. (26)	145°	145° & 175°	1000 Hz	5 SD BW	Net	Unfiltered	PRFD RFD <sub>100</sub> RFD <sub>150</sub> RFD <sub>200</sub>
Leary et al. (42)	142 ± 7°	146 ± 11°	1000 Hz	---		Rectangular smoothing with a moving half-width of 12	PRFD RFD <sub>30, 50, 90, 100, 150, 200, 250</sub>

--- = not stated

¥ = Incorrectly cites joint angles 'in line with previous research' when the referenced studies used different joint angles

Net Force = Gross Force – Body Weight

PRFD = Peak Instantaneous RFD (the greatest rate of change in force between two tangential points; the window differs based on sampling frequency)

Mean force (Change in force / change in time from onset of force production to time to peak force)

RFD<sub>100</sub> = subscript numbers refer to the epoch for mean RFD

\*Based on knee angle achieved during the 2<sup>nd</sup> pull phase of the clean for each individual

#Published abstract

\* Self-selected to replicate the start of the second pull

BW = Body weight (during the initial period of quiet standing), SD = standard deviation

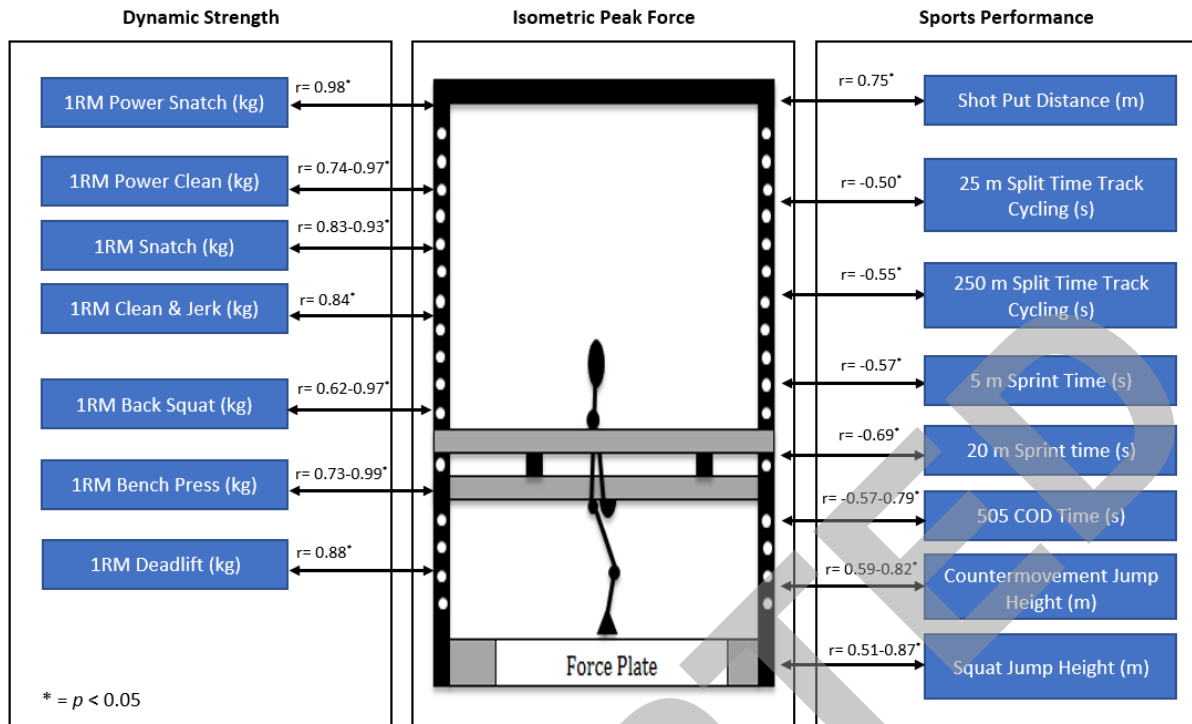


Figure 1: Relationships between isometric mid-thigh pull peak force and performance in other tasks (References in Table 1)



ACCEPTED

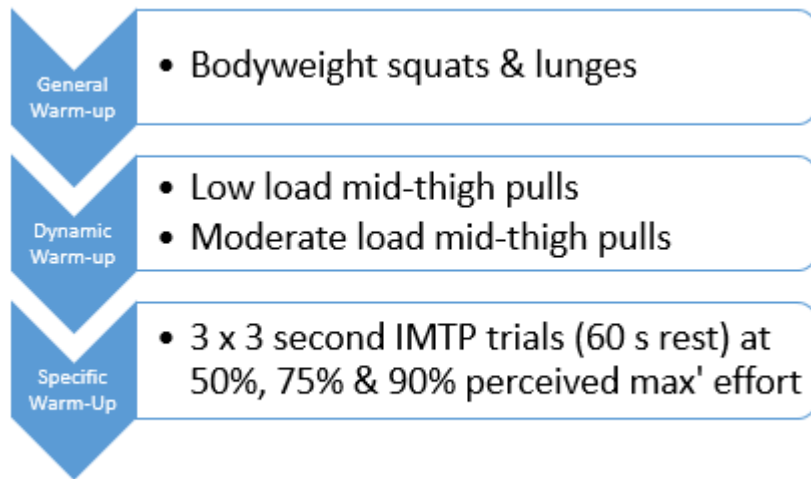
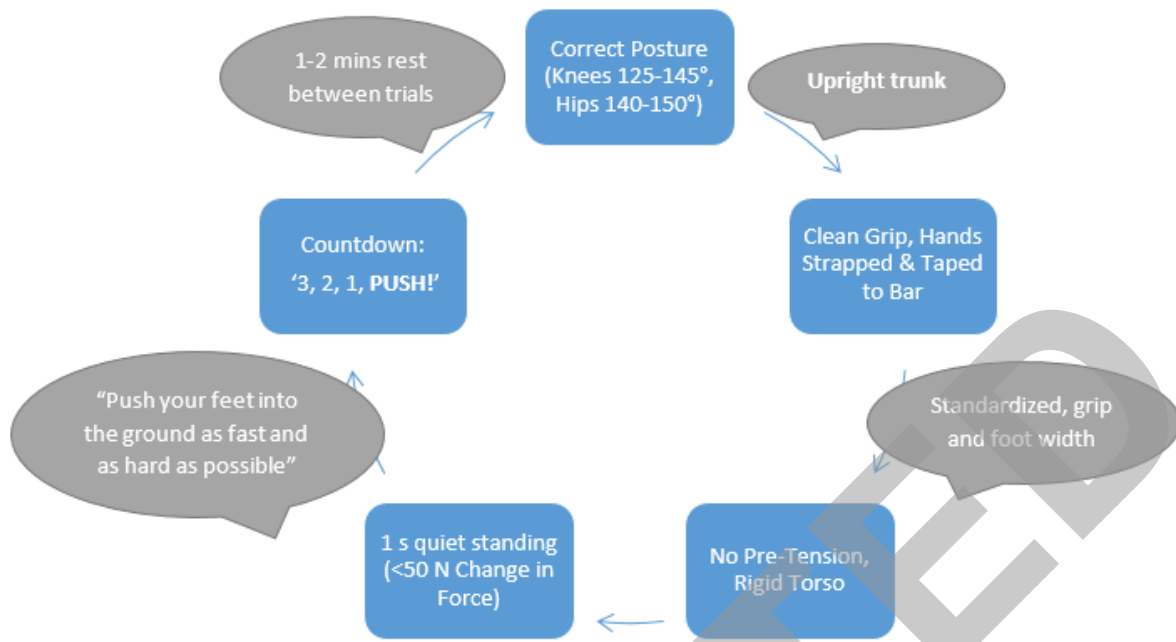


Figure 3: Standardized Warm Up Procedure

ACCEPTED



**Acceptable trials <250 N difference in peak force, minimal pre-tension (<50 N) or counter-movement at the start**

Figure 4: Standardized isometric mid-thigh pull testing procedure

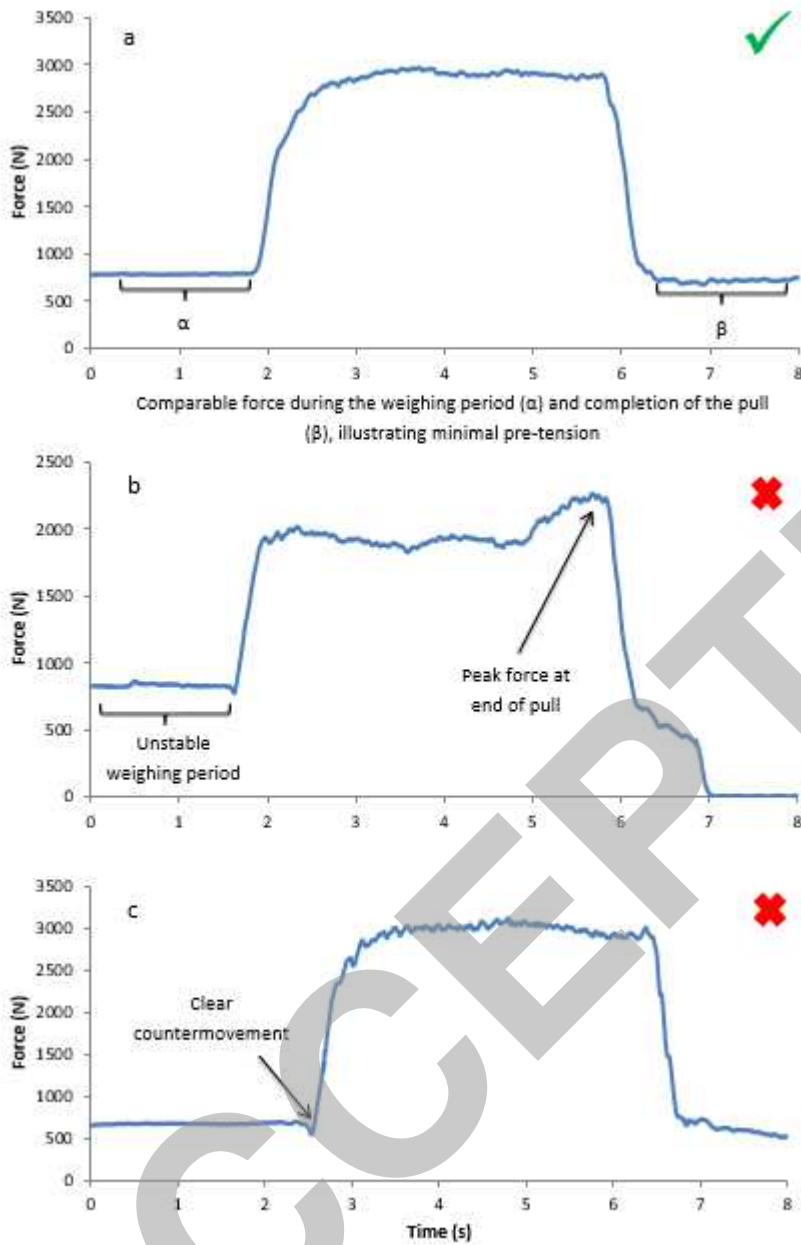


Figure 5: Examples of acceptable and unacceptable isometric mid-thigh pull force-time traces







ACCEPTED





ACCEPTED





ACCEPTED