Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001968

Title of the Article: Effect of Body Position on Force Production During the Isometric Mid-Thigh Pull

Submission Type: Original Investigation

George K. Beckham[1,2], Kimitake Sato[2], Satoshi Mizuguchi[2], G. Gregory. Haff[3], Michael H. Stone[2]

[1]: Kinesiology Department, California State University, Monterey Bay, Seaside, CA.

[2]: Center of Excellence for Sport Science and Coach Education, Department of Exercise and Sport Science, East Tennessee State University, Johnson City, TN.

[3]: Center for Exercise and Sport Science Research, Edith Cowan University, Joondalup, Australia.

Corresponding Author

George K. Beckham
gbeckham@csumb.edu
Phone: (831)582-5258
Fax: (831) 582-3737
100 Campus Center
Valley Hall D
Seaside, CA 93955

Preferred Running Head: Isometric Mid-Thigh Pull Body Position

Author Statement:

The following manuscript has been read and approved by all of the listed co-authors and meets the guidelines of co-authorship. No funding was received for this study.

Conflicts of Interest:

The authors have no conflicts of interest to report.

Abstract word count: 199

Number of Figures and Tables: 7

ABSTRACT

Various body positions have been used in the scientific literature when performing the isometric mid-thigh pull resulting in divergent results. We evaluated force production in the isometric mid-thigh pull in bent (125° knee and 125° hip angles) and upright (125° knee, 145° hip angle) positions in subjects with (>6 months) and without (< 6 months) substantial experience using weightlifting derivatives. A mixed-design ANOVA was used to evaluate the effect of pull position and weightlifting experience on peak force, force at 50ms, 90ms, 200ms, and 250ms. There were statistically significant main effects for weightlifting experience and pull position for all variables tested, and statistically significant interaction effects for peak force, allometricaly scaled peak force, force at 200ms, and force at 250ms. Calculated effect sizes were small to large for all variables in subjects with weightlifting experience, and were small to moderate between positions for all variables in subjects without weightlifting experience. A central finding of the study is that the upright body position (125° knee and 145° hip) should be used given that forces generated are highest in that position. Actual joint angles during maximum effort pulling should be measured to ensure body position is close to the position intended.

Key words: maximum strength, performance testing, weightlifting, test variability, strength testing

INTRODUCTION

Maximal strength testing is a valuable method for evaluating athletes and monitoring training adaptations (19). While maximal strength is commonly assessed using 1-repetition maximum testing (1-RM), other means of evaluating maximal strength have recently been suggested to be equally or more efficacious and efficient (19). One such method is the isometric mid-thigh pull (IMTP), which has significant advantages over 1-RM testing, such as less time spent testing, reduced training volume, reduced accumulated fatigue, and potentially being safer than 1-RM testing. Additionally, strong correlations between IMTP variables and dynamic movements such as the 1-RM back squat, snatch and clean have been reported (2, 21).

The original research on the IMTP selected a body position that mimicked the second pull of the clean (9). This position was selected because the highest forces and bar velocities are generated during this phase of weightlifting movements (14). However, as the IMTP has increased in popularity as a performance test, there have been inconsistencies in the methods used for performing the test. In particular, the precise posture and body position used in previous studies has not always accurately represented the second pull position used in the original research. Most studies have used a knee angle of approximately 120°-135° (2, 3, 8, 12, 15, 21), while there has been substantial variability in what hip angle has been used in the studies that have reported it (several studies have not reported the hip angle used in testing) (16-18).

To examine the question of whether the hip and knee angle used during the IMTP affects force production, Comfort et al. (6) evaluated changes in force production between 9 different hip and knee angles, and found that there were no differences between each position. Another study by Beckham et al. (3) found conflicting results in powerlifters, who had higher peak forces in an upright torso IMTP position compared to a bent-over torso position (neutral spine, but greater hip flexion). Given that these two studies offer divergent findings, there is not consensus in the scientific literature on the impact of body position on forces generated during the IMTP.

If body position does influence the force produced during the test, then it becomes substantially more difficult to compare the results between studies that use different body positions. Additionally, within the same study, if there is a large variation between subjects in the body positions used, then an additional source of measurement error and variability in force production has been included in IMTP measurement making it more difficult to draw accurate conclusions about a group of subjects' performance capacities. However, if body position does not result in differences in force production, then it is not a source of error in the prior two scenarios.

Experience with weightlifting derivatives (derivatives of the snatch and clean, e.g. mid-thigh pulls, power cleans or power snatches)(22) may exert a potential influence on the impact of body position on force production during the IMTP test. Generally, weightlifters produce the highest forces during the second pull phase of the clean and perform training exercises to maximize their abilities in this position (10). Because the IMTP was originally based on a position similar to the second pull of the clean, it is plausible that significant training experience with the second pull position would influence how effective one might be with that pulling position. Thus, it is worthwhile to evaluate the potential influence of experience with weightlifting derivatives on force production differences between body positions.

The purpose of this study was to evaluate the effects of body position and experience with weightlifting movements on force production in isometric mid-thigh pull. We hypothesized that the upright body position would result in higher forces generated during the IMTP, and that experience with weightlifting derivatives would increase this difference.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

The present study was conducted in two parts in order to examine the impact of body position and training experience on the performance of the IMTP. For part 1 of this study, the use of an upright and bent body position during the IMTP were evaluated in subjects with and without experience with weightlifting or weightlifting derivatives. Part 2 of the study was a second data collection and data analysis period that was performed while attempting to use the IMTP methods specifically outlined by Comfort et al.(6). This was undertaken in an attempt to replicate Comfort et al.'s (6) findings and compare to the findings of part 1 of the present study.

PART 1: SUBJECTS

Two groups of subjects were recruited for this study. All subjects, regardless of group were required to be male and involved in regular physical activity. One group had greater than 6 months of experience training with weightlifting movements. This group was designated the "experience with weightlifting" group (n=12, body mass: 84.4±7.4kg, years of weightlifting: 4.9±4.2y range: 1.07-13.5y). The other group, with less than 6 months experience training with weightlifting movements, was designated the "low experience with weightlifting" group (n=10, body weight: 75.1±11.5kg, years of weightlifting: 0.09±0.09y range: 0.00-0.24y). Prior to participation, all subjects were thoroughly informed of study procedures. Each subject then read and signed informed consent documents according to procedures outlined by the University Institutional Review Board and in accordance with the Declaration of Helsinki. All subjects were free from musculoskeletal injury for at least 6 months prior to testing.

PART 1: PROCEDURES

Subjects came into the laboratory on 5 separate occasions, separated by 72-96 hours. In each session, subjects performed the IMTP in a custom-designed power rack (Sorinex, Irmo, SC) that allows the bar to be fixed at any height, while standing on two adjacent force plates (45.5 cm x 91 cm, RoughDeck HP; Rice Lake Weighing Systems). Subjects were secured to the bar using lifting straps and athletic tape in accordance with previous methods.(9)

In the first testing session, bar heights and foot position were determined and recorded for the upright and bent positions so that they could be replicated in each subsequent session. The bar heights to allow for each body position were determined in the first testing session by using a digital camera (HD Pro Webcam C920, Logitech Inc.) and freely available angle measurement software (Screen Scales, Talon Designs LLP). When initially measuring bar heights and joint angles in the first familiarization session, subjects were instructed to pull on the bar with 50% effort in an effort to remove slack from the body.

Subjects performed IMTP trials in each session as outlined by Figure 1. Procedures were identical on each day of testing, except that the pull position order was randomized to remove testing order bias. Only data collected on the fifth and final session were used for this study.

Two separate pulling positions were evaluated during the IMTP in randomized order. Specifically, a body position which allowed a knee angle of 125° and hip angle of 145° was designated the "upright" position, and a body position which allowed a knee angle of 125° and hip angle of 125° was designated the "bent" position. The knee angle of 125° represents the approximate angle commonly used in IMTP studies (2, 3, 8, 12, 15, 21). The two hip angles were meant to approximate the upright body position used in many studies (2, 15, 21), while the bent position was meant to approximate the body position used in others (6, 16).

On each testing day, subjects performed a standardized warmup of 2 minutes of cycling at 50 watts with 50 to 60 RPM. Subjects then performed 6 repetitions each of: forward walking lunges, reverse walking lunges, side lunges, straight leg march, and quadriceps pulls, then 5 bodyweight squats and 5 ballistic bodyweight squats. This standard warmup was specifically chosen to reduce the possibility that the warmup would preferentially benefit either pulling position. After the warmup, the order, intensity and rest of IMTPs went according to procedures outlined in Figure 1.

Figure 1 about here

To ensure there was minimal slack in the body before initiation of the pull, subjects were instructed to use a minimal of pre-tension (2). Once in position (verified by viewing the subject and stability of the force trace), subjects received a countdown to begin the pull and were instructed when to stop in accordance with previous methods (9). For all maximum effort pulls, subjects received substantial encouragement by the investigators to ensure a maximal effort. Before each pull, subjects were instructed to “pull as hard and fast as possible” to maximize rate of force development and peak force (4).

On sessions 1, 3, and 4, subjects only performed two maximal effort pulls, while on sessions 2 and 5, subjects performed between 2 and 4 pulls. Ideally, subjects needed only to perform 2 pulls on sessions 2 and 5, but maximum effort attempts were repeated if errors in pulling were observed (countermovement or a substantial change in body position) or if a ≥250N difference in peak force were measured (9, 15). If 4 trials were needed, the best 2 trials were used for analysis. Only the data from testing session 5 was used for the present study.

Analog data from the force plate were amplified and low-pass filtered at 16 Hz (Transducer Techniques, Temecula, CA), and sampled at 1000 Hz (DAQCard-6063E, National Instruments). Force-time curves were digitally filtered using a 2nd order Butterworth low-pass filter at 10 Hz and analyzed using a custom Labview program (Labview 2010, National Instruments). The following variables were calculated from the force time curve generated during each pull, peak force (PF), and force at various time points after the initiation of the pull including force at 50ms (F50), force at 90ms (F90), force at 200ms (F200), and force at 250ms (F250). The start of each pull was identified by visual inspection. In addition, peak force was scaled allometrically to account for body mass differences, using the equation $force \cdot bodymass^{-0.67}$ (13).

Sagittal plane video was recorded for each pull (HD Pro Webcam C920, Logitech Inc.). Joint angles for the knee and hip were evaluated at the start (just before initiation of the pull), and most extreme (point at which joint angles were at their maximum during the pull).

PART 1: STATISTICAL ANALYSIS

All data were screened for within-session test-retest reliability, outliers and normality. Reliability was assessed using ICCs with 95% CI, and CV with 95% CI (typical error of log-transformed data). Each reliability metric was calculated on the entire group, as well as each subset of data (group and position). Data were also screened for violations of assumptions for a mixed-design ANOVA (23).

Multiple 2x2 mixed ANOVAs (weightlifting experience X pulling position) were run to determine differences between groups and position for each variable tested. Generalized eta-squared (η_g^2) was used for effect sizes and interpreted with the following scale: 0.02 small, 0.13

medium, and 0.26 large (1, 5). In Study 1, The Hedge's g correction for small sample sizes of Cohen's d effect size statistics were calculated between pulling positions for the experienced and inexperienced groups. The magnitude of effect sizes was interpreted according to a scale by Hopkins (11) as follows: 0 trivial, 0.2 small, 0.6 moderate, 1.2 large, and >2.0 very large. All analysis was performed in R (The R Foundation for Statistical Computing, Vienna Austria), using the 'psych', 'effsize', 'pastecs' and 'ezANOVA' analysis packages (20).

PART 1: RESULTS

PF, F50, F90, F200, and F250 were adequately reliable for later analysis. Reliability statistics can be found in Table 1. Descriptive statistics for IMTP variables can be found in Table 2.

Insert Table 1 and Table 2 About Here

Specific results from each of the repeated measures ANOVAs can be found in Table 3. Pairwise effect size statistics between pulling positions are found in Figure 2. The statistical interaction effect showed the general pattern that experienced lifters produced greater values in the upright position than inexperienced lifters in PF, PFa, F200, and F250. For the variables F50 and F90, while an interaction effect was not present, there was a main effect for position, indicating greater values in the upright position when both experience groups were combined. Furthermore, regardless of the presence of a statistical interaction effect, all variables showed a moderate or small effect in favor of the upright position in the experienced and the inexperienced groups, respectively, although the 95% confidence intervals of the two groups overlapped (Figure 2).

Sagittal plane angle data for the hip and knee for each IMTP position are reported in Table 4. Small amounts of extension during the pull were observed for the knee and hip for both the bent and upright pulling positions.

Insert Table 3 and Table 4 About Here

Insert Figure 2 About Here

<u>PART 2: METHODS</u>

<u>PART 2: SUBJECTS</u>

Subjects for Study 2 were experienced with both weightlifting (>6 months) and the IMTP in both positions. Subjects were fully informed about study procedures, and gave their informed consent to participate. A total of 8 subjects were initially recruited for testing, however two subjects were unable to achieve positions outlined above. Specifically, these two subjects were unable to achieve the prescribed position and maintain the bar position in alignment with the thigh mark. Another subject increased his hip angle from 125° to 140° during the bent pull, and was therefore excluded on the basis that this did not represent the bent position. Thus, force data for five subjects were analyzed.

PART 2: PROCEDURES

Part 2 of this study was performed after the completion of part 1 of this study when it was determined that part 1 had different findings than those reported by Comfort et al. (6) on the impact of knee and hip angle on IMTP force-time curve variables. Statistically significant differences between testing positions for all variables tested were observed in part 1, but differences were not found in the study by Comfort et al. (6). Slight changes in positioning and set up were made after further comparison between the methods of part 1 and correspondence with the Comfort et al. (6) in order to ensure a more accurate replication of their original work. To evaluate if differences in findings between part 1 and the study by Comfort et al. (6) were due to slight differences in bar positioning on the thigh between both studies (despite similar knee and hip angles used in both studies), the following changes to testing procedures were introduced for part 2 based upon direct communication with Comfort et al. (6) about their research:

1. A horizontal line was drawn in marker across the thighs marking exactly half the distance between the anterior superior iliac spine and center of the patella. When setting up the subject within the custom power rack, the bar had to cover the line drawn on the thigh.
2. Foot movement was not allowed to deviate between the two body positions.

All IMTPs were performed in a single session, with each pull position performed in randomized order. Subjects' thighs were marked as outlined above and each entered the rack to measure bar heights for each position. Bar heights and joint angles were determined in the same manner as to Part 1. Warmups, rest periods and maximum effort pulls were structured identically to methods used in Part 1.

PART 2: STATISTICAL ANALYSIS

Absolute differences were calculated between each position on an individual basis so that individual changes between positions could be quantified. Hedge's g and 95% confidence interval was calculated for the group changes.

PART 2: RESULTS

Comparisons of results between each pulling position can be found in Table 5. Each subject improved performance in the upright position for nearly all variables measured, with three subjects improving in all variables measured. Effect size and 95% confidence interval between positions (negative effect size indicating that values for the upright position were larger) for PF, F50, F90, F200, and F250 were: -0.59 (-1.86-0.67), -0.19 (-1.43-1.05), -0.35 (-1.06-0.9), -0.54 (-1.81-0.72), and -0.63 (-1.9-0.64).

Table 5 & 6 about here

DISCUSSION

The main findings of this two-part study are that there are differences in the force production capabilities for subjects when performing the IMTP with different body positions. More specifically, the upright position appears to be the position in which subjects can create higher forces more quickly. The magnitude of force production difference between the bent and upright positions does depend on whether subjects are experienced with weightlifting or not, as indicated by the statistically significant interaction effect, and the generally lower effect sizes between pulling positions for the subjects with less experience with weightlifting derivatives. Subjects who are experienced with weightlifting exhibit greater differences between the two positions, as indicated by the moderate to large effect sizes observed (g = 0.6-1.2). Subjects without weightlifting experience still exhibited differences in force generation capacity between the two positions as indicated by the small to moderate effect sizes (g = 0.3-0.8) between positions.

From a specificity perspective, it is understandable that the weightlifting-experienced group would perform better in the body position that mimics the second pull of the clean or snatch (upright position). The phase of the clean and snatch with the highest forces is the second pull (10), which is represented by the upright position used in the present study and previously published research (8). Since weightlifters frequently train with exercises that require and develop mastery of this position it is possible that they have maximized their ability to develop forces in this position. It is not unexpected that the bent over position results in reduced force production as it corresponds to the transition phase which links the first and second pull in weightlifting movements. Overall, the transition phase of the pulling motion always exhibits the lowest forces as a result of the mechanical disadvantages associated with the position in weightlifting (10). Conceptually, the transition phase functions to reposition the body and prepare the lifter for execution of the second pull where she or he is able to maximize force generation (7). The increased force production may be due to better mechanical advantage, muscle lengths, and potentially engagement of the stretch-shortening cycle, although only the former two factors would be afforded to force production in the IMTP, given its isometric execution.

For subjects with less weightlifting experience, it would make sense that there is a reduced difference between the tested positions. These subjects would have spent less time (if any time at all) overloading the power position and second pull, and would not be expected to display the effects of training this position. There is however, still an apparent mechanical advantage when using the upright position even among those subjects who are less experienced with weightlifting movements. Despite the training difference between the two groups, there were still moderate effect sizes between positions. Similarly, a previously published study evaluated the differences in IMTP and a bent-over deadlift-style "lockout" technique on force production capacity with powerlifters (3). Despite the powerlifters' lack of experience performing weightlifting movements (i.e. snatch, clean and jerk) and weightlifting derivatives (e.g. mid-thigh pulls), and the large training volumes the lifters had spent practicing deadlift and overloading the deadlift lockout positions, there was still a statistically significant difference ($p<0.001$) in peak force production between the upright and bent positions and a large effect size ($d = 1.23$).

While the positions used in part 1 of the present study closely mimicked some of the positions used in a study by Comfort et al.(6), force-production differences were observed between the bent and upright positions. Because we did not use specific nuances of methods that were later communicated to us by the authors in part 1, we attempted to replicate exactly the methods used by Comfort et al. (6) in part 2, in order to address the possibility that the method of positioning in part 1 could account for the observed differences. Despite the changes in part 2, and having similar training backgrounds to those of Comfort et al. (6), force production differences remained for the later time points (F200, F250, PF) for all subjects (Hedge's g of -0.54, -0.63 and -0.59, for F200, F250, and PF, respectively). For early time points (F50, F90), for 3 of 5 subjects the upright position had substantially greater force values, while the other two subjects there were only small differences favoring the upright position (Hedge's g of -0.19 and -0.35 for F50 and F90, respectively).

While it is difficult to speculate why no statistical differences in force production between body positions were found in the study by Comfort et al. (6), some possibilities exist. For example, in all of our subjects during the bent position pulls, we observed (from direct observation and video) that nearly all subjects attempted to adjust body position into one resembling the upright position. The increase in joint angles during the pull confirms this observation. In addition, in part 2 of the present study, one of our subjects was unable to maintain the bent position, and immediately shifted during the pull to one that closely resembled the upright position, and was thus excluded from the study. Two more subjects were unable to achieve the correct bent position as specified in the Comfort et al. (6) study, without bending their arms or elevating their shoulder girdle. Had these subjects pulled in the bent position, it seems likely they would have increase their hip angle substantially as their elbows extended and shoulder girdle depressed, ending in a body position similar to that of the other excluded subject. While we are unable to verify if the same body movement issues occurred in the Comfort et al.(6) study, it is at least plausible that some amount of angle change occurred, allowing for the force production between positions to be similar.

One particularly interesting finding in the present study is that there is a small amount of extension that occurs at the knee and the hip during the execution of the IMTP (observed with video). While every attempt was made to have the subjects position themselves while using pre-tension to minimize slack in the body, the high forces produced during the pull exceed those of pre-tension used to determine position by a large margin. It is possible that these high forces lead to some slight repositioning of the body (e.g. depression of scapula) and change in length of elastic tissues (e.g. decreased height of intervertebral discs, elongation of muscles or ligaments), allowing for some degree of increased knee and hip angle. We attempted to reduce this "slack" as much as possible prior to initiation of the pull, but it was apparent that the "pretension" that subjects applied to the bar when setting up their body positions may not have been enough. Subjects did however achieve the desired body position at some point during the pull, whether it was at the start, during the pull, or at the peak extended position. This finding emphasizes the importance of ensuring that very little slack is in the body when determining starting body position and bar height, as well as prior to measured isometric pulls.

Some recent research has begun using a "self-selected" position when executing the IMTP (24, 25). One potential issue with using a non-standardized position is that different subjects may be performing worse than would be possible using a standardized and optimal (from a force production perspective) position, especially so if the subject's chosen position is more bent over than it is upright. The present study indicates that body positioning during the IMTP does matter to force production. Should the "self-selected" position used by any given individual vary between individuals or vary over time in a repeated measures design, it may result in latent variability in performance of which the presence and magnitude is unknown to the researchers. This adds a potentially large source of error into values obtained from the IMTP, thus a self-selected body position is not recommended.

CONCLUSION

The findings of this study indicate that the body position in which the IMTP is executed matters to force production, especially so for subjects with experience with weightlifting derivatives. Furthermore, studies should report both the knee and hip angles used by their subjects for greater ease in comparing results between studies.

PRACTICAL APPLICATIONS

In future studies or in practice, we recommend the IMTP be performed with a 120-135° knee angle, and approximately a 140-150° hip angle (upright torso). Bar heights and body positions should be verified under tension, and researchers should expect joint angles to increase slightly during the pull. Consistent bar heights and joint angles should be used when testing over time to ensure that the effect of body position is accounted for.

REFERENCES

1. Bakeman R. Recommended effect size statistics for repeated measures designs. *Behav Res Methods* 37: 379-384, 2005.
2. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey M, Lamont H, Hornsby G, Haff G, and Stone M. Relationships of isometric mid-thigh pull variables to weightlifting performance. *J Sports Med Phys Fitness* 53: 573-581, 2013.
3. Beckham GK, Lamont HS, Sato K, Ramsey MW, Haff GG, and Stone MH. Isometric strength of powerlifters in key positions of the conventional deadlift. *J Trainology* 1: 32-35, 2012.
4. Bemben MG, Clasey JL, and Massey BH. The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. *Res Q Exerc Sport* 61: 96-99, 1990.
5. Cohen J. *Statistical power analysis for the behavioral sciences.* 1988.

6. Comfort P, Jones PA, McMahon JJ, and Newton R. Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *Int J Sports Physiol Perform* 10: 58-63, 2015.

7. Enoka RM. The pull in olympic weightlifting. *Med Sci Sports* 11: 131-137, 1979.

8. Haff GG, Carlock JM, Hartman MJ, Kilgore JL, Kawamori N, Jackson JR, Morris RT, Sands WA, and Stone MH. Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. *J Strength Cond Res* 19: 741-748, 2005.

9. Haff GG, Stone M, O'Bryant HS, Harman E, Dinan C, Johnson R, and Han K-H. Force-Time Dependent Characteristics of Dynamic and Isometric Muscle Actions. *J Strength Cond Res* 11: 269-272, 1997.

10. Häkkinen K, Kauhanen H, and Komi PV. Biomechanical changes in the olympic weightlifting technique of the snatch and clean & jerk from submaximal to maximal loads. *Scand J Sports Sci* 6: 57-66, 1984.

11. Hopkins WG. A scale of magnitude for effect statistics. 2014.

12. Hornsby WG, Haff GG, Sands WA, Ramsey MW, Beckham GK, and Stone MHE. Alterations in strength characteristics for isometric and dynamic mid-thigh pulls in collegiate throwers across 11 weeks of training. *Gazz Med Ital* 172: 929-940, 2013.

13. Jaric S, Mirkov D, and Markovic G. Normalizing physical performance tests for body size: a proposal for standardization. *J Strength Cond Res* 19: 467-474, 2005.

14. Kauhanen H, Häkkinen K, and Komi PV. A biomechanical analysis of the snatch and clean & jerk techniques of Finnish elite and district level weightlifters. *Scand J Sports Sci* 6: 47-56, 1984.

15. Kraska JM, Ramsey MW, Haff GG, Fethke N, Sands WA, and Stone MH. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform* 4: 461-473, 2009.

16. McGuigan MR, Newton MJ, and Winchester JB. Use of isometric testing in soccer players. *J Aust Strength Cond Assoc* 16: 11-14, 2008.

17. McGuigan MR and Winchester JB. The relationship between isometric and dynamic strength in college football players. *J Sport Sci & Med* 7: 101-105, 2008.

18. McGuigan MR, Winchester JB, and Erickson T. The importance of isometric maximum strength in college wrestlers. *J Sports Sci Med* 5: 108-113, 2006.

19. McMaster DT, Gill N, Cronin J, and McGuigan M. A brief review of strength and ballistic assessment methodologies in sport. *Sports Med* 44: 603-623, 2014.

20. R Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria, 2016.

21. Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, and Newton RU. Relationship of maximum strength to weightlifting performance. *Med Sci Sports Exerc* 37: 1037-1043, 2005.

22. Suchomel TJ, Comfort P, and Stone MH. Weightlifting pulling derivatives: rationale for implementation and application. *Sports Med* 45: 823-839, 2015.

23. Tabachnick B and Fidell L. *Experimental Design Using Anova*. Belmont, CA: Duxbury/Thomson, 2007.

24. Thomas C, Comfort P, Chiang C-y, and Jones PA. Relationship between isometric mid-thigh pull variables and sprint and change of direction performance in collegiate athletes. *J Trainology* 4: 6-10, 2015.

25. Thomas C, Jones PA, and Comfort P. Reliability of the Dynamic Strength Index in collegiate athletes. *Int J Sports Physiol Perform* 10: 542-545, 2015.

Table 1: Reliability results for each subset of analysis

Tested Variable	Group	Position	ICC	ICC 95% CI	CV	CV 95% CI
Peak Force	Both	Both	0.991	0.991-0.991	3.4	2.8-4.3
	Exp	Bent	0.986	0.986-0.987	2.7	1.9-4.6
		Upright	0.997	0.996-0.997	1.9	1.3-3.2
	Inexp	Bent	0.964	0.962-0.965	5.5	3.8-10.3
		Upright	0.984	0.984-0.985	2.8	1.9-5.1
Force at 50ms	Both	Both	0.948	0.947-0.949	8.0	6.6-10.2
	Exp	Bent	0.803	0.796-0.811	8.9	6.2-15.5
		Upright	0.946	0.944-0.948	7.4	5.2-12.8
	Inexp	Bent	0.903	0.899-0.907	9.6	6.5-18.2
		Upright	0.951	0.949-0.953	7.0	4.8-13.2
Force at 90ms	Both	Both	0.955	0.954-0.956	8.4	6.9-10.7
	Exp	Bent	0.706	0.694-0.717	12.1	8.4-21.4
		Upright	0.979	0.979-0.98	5.7	4-9.9
	Inexp	Bent	0.939	0.936-0.941	8.9	6-16.8
		Upright	0.970	0.968-0.971	6.0	4.1-11.2
Force at 200ms	Both	Both	0.977	0.977-0.978	5.9	4.9-7.5
	Exp	Bent	0.943	0.941-0.945	5.2	3.7-9
		Upright	0.979	0.978-0.98	5.5	3.8-9.4
	Inexp	Bent	0.894	0.889-0.899	7.9	5.4-14.9
		Upright	0.961	0.959-0.963	4.7	3.2-8.8
Force at 250ms	Both	Both	0.984	0.984-0.985	4.4	3.6-5.6
	Exp	Bent	0.977	0.976-0.977	3.3	2.4-5.8
		Upright	0.977	0.976-0.977	4.6	3.2-7.9
	Inexp	Bent	0.946	0.944-0.949	5.2	3.5-9.6
		Upright	0.955	0.953-0.957	4.3	2.9-8

Exp: Experienced with weightlifting variations. Inexp: Inexperienced with weightlifting variations. ICC: Intraclass correlation, CV: Coefficient of variation, CI: confidence interval

Table 2: Force results from isometric mid-thigh pulls in different body positions

		PF	PFa	F50	F90	F200	F250
Bent	Exp	3660.7 ±612.4	190.8 ±31.4	1724.5 ±242.5	2058.2 ±323.5	2635 ±435.3	2722.3 ±425.1
	Inexp	3108.3 ±677.8	174.2 ±29.0	1330.8 ±251.8	1592.1 ±351	2087.9 ±360.2	2213.8 ±349.9
Upright	Exp	4587.1 ±981.8	238.9 ±49.9	1920.3 ±395.5	2441.2 ±562	3275.1 ±714	3421.7 ±688.6
	Inexp	3493.9 ±568.2	196.5 ±22.8	1424.3 ±295.1	1755.5 ±399.2	2297.4 ±388.1	2401.3 ±349.1

Exp: Experienced with weightlifting variations. Inexp: Inexperienced with weightlifting variations. PF: peak force, PFa: allometrically scaled peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, F250: force at 250ms.

Table 3: Results of repeated measures ANOVAs

	Main Effects		Interaction
Variable	Group	Pull Position	Group by Pull Position
Peak Force	F(1,20)=14.9, *p*=0.012*, η_g^2=0.25	F(1,20)=45.7, p<0.001*, η_g^2=0.14	F(1,20)=7.8, p=0.01*, η_g^2=0.03
Peak Force (allometrically scaled)	F(1,20)=4.3, p=0.052, η_g^2=0.15	F(1,20)=45.8, p<0.001*, η_g^2=0.18	F(1,20)=6.2, p=0.022*, η_g^2=0.029
Force at 50ms	F(1,20)=12.7, p=0.002*, η_g^2=0.37	F(1,20)=14.2, p=0.001*, η_g^2=0.04	F(1,20)=4.5, p=0.20, η_g^2=0.00
Force at 90ms	F(1,20)=11.5, p=0.002*, η_g^2=0.33	F(1,20)=18.5, p=0.003*, η_g^2=0.07	F(1,20)=3.0, p=0.10, η_g^2=0.01
Force at 200ms	F(1,20)=13.7, p=0.001*, η_g^2=0.37	F(1,20)=41.5, p<0.001*, η_g^2=0.1	F(1,20)=10.7, p=0.004*, η_g^2=0.03
Force at 250ms	F(1,20)=14.8, p=0.001*, η_g^2=0.39	F(1,20)=55.5, p<0.001*, η_g^2=0.12	F(1,20)=18.5, p<0.001*, η_g^2=0.04

** Denotes statistically significant at p<0.05*

Table 4: Joint angle data measured for isometric mid-thigh pulls in each body position

	Knee			Hip		
	Start (°)	Maximum(°)	Change(°)	Start (°)	Maximum(°)	Change(°)
Bent	122.5±7.3	127.3±5.3	5.0±3.3	120.3±6.9	128.7±6.5	7.4±3.8
Upright	120.9±5.2	127.8±5.2	7.0±3.4	138.1±8.9	148.5±6.8	10.4±6.4

Change in angle is the total joint angle change from the starting position of the IMTP (Start) to the highest joint angle observed (Maximum) during the IMTP

Table 5: Comparison of between force variables for each isometric mid-thigh pull position for each subject

		Subject				
		1	2	3	4	5
PF	Bent	3171	4491	2410	3738	5056
	Upright	3940	4992	3068	4018	6084
	Difference	-769	-501	-658	-280	-1028
F50	Bent	1866	2579	1099	1522	1943
	Upright	1830	2527	1227	1692	2233
	Difference	36	52	-128	-170	-290
F90	Bent	2261	3387	1384	1954	2217
	Upright	2275	3308	1729	2124	2951
	Difference	-14	79	-345	-170	-734
F200	Bent	2682	4016	1956	2619	3320
	Upright	2992	4588	2360	2785	4238
	Difference	-310	-572	-404	-166	-918
F250	Bent	2734	4036	2035	2824	3529
	Upright	3222	4831	2480	3019	4328
	Difference	-488	-795	-445	-195	-799

PF: peak force, PFa: allometrically scaled peak force, F50: force at 50ms, F90: force at 90ms, F200: force at 200ms, F250: force at 250ms.

Table 6: Individual joint angle data from each subject for each isometric mid-thigh pull position

	Subject	Knee Start (°)	Knee Max (°)	Knee Change (°)	Hip Start (°)	Hip Max (°)	Hip Change (°)
Bent	1	111.5	121.0	9.5	117.0	122.0	5.0
	2	125.0	131.0	6.0	126.0	130.0	4.0
	3	127.0	127.0	0.0	117.5	123.0	5.5
	4	118.0	122.0	4.0	124.0	135.0	11.0
Upright	1	115.0	126.0	11.0	133.0	139.0	6.0
	2	122.5	131.0	8.5	143.0	147.0	4.0
	3	123.5	126.0	2.5	137.5	147.0	9.5
	4	117.5	128.5	11.0	142.5	154.0	11.5

Angle data is missing for subject 5 due to corrupted video file. Change in angle is the total joint angle change from the starting position of the IMTP (Start) to the highest joint angle observed (Maximum) during the IMTP

First position

- -50% effort pull 2.5 s
- -1 min rest
- -50% effort pull 2.5 s
- -1 min rest
- -75% effort pull
- -1 min rest
- -75% effort pull 2.5 s
- -1 min rest
- -100% effort pull 2.5 s
- -2 min rest
- -100% effort pull 2.5 s
- -3 min rest

Repeat with second position

Figure 1: Testing Progression of IMTPs

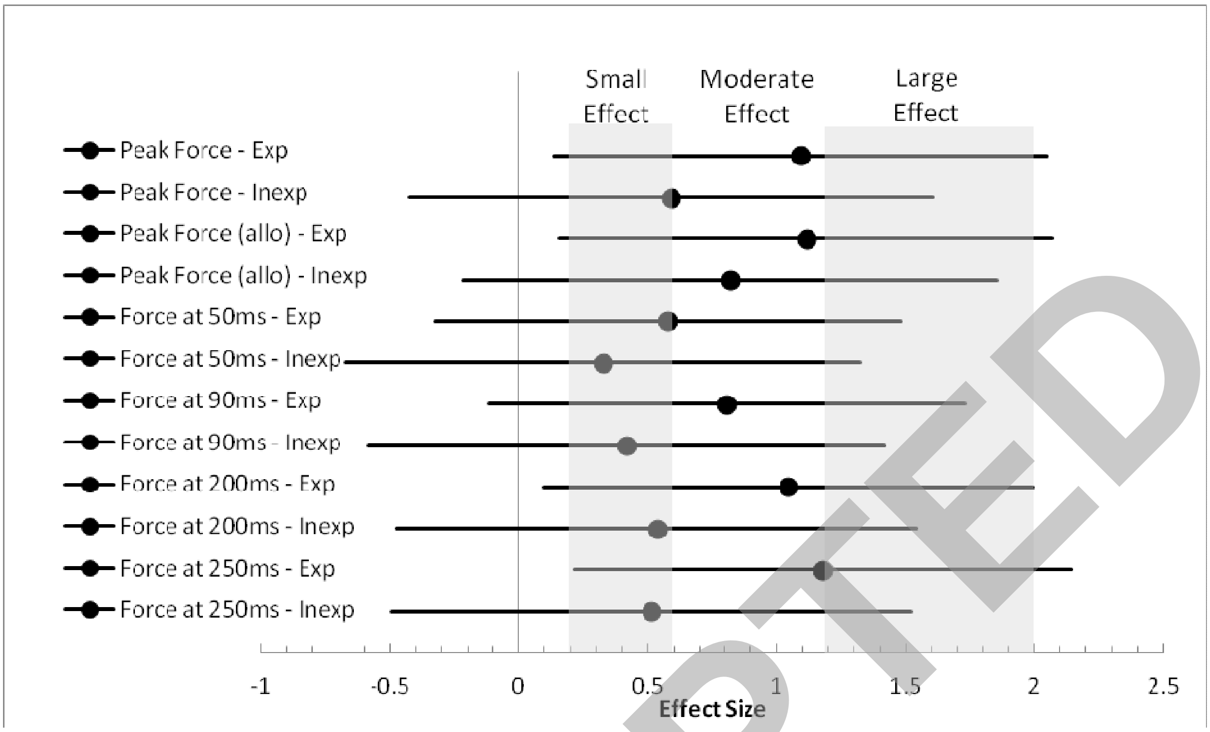

Figure 2: Hedge's g effect sizes between IMTP body positions with 95% confidence intervals. Exp: experienced with weightlifting group, Inexp: inexperienced with weightlifting group