PEAK LOWER EXTREMITY NET JOINT MOMENTS AND JOINT ANGLES DURING ISOMETRIC MID-THIGH PULLS VARY WITH BAR POSITION

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The purpose of this study was to identify the effect of bar position on the ankle, knee, and hip peak net joint moments (NJM) and associated joint angles during isometric mid-thigh pulls (IMTP). Seven female college lacrosse players performed maximal IMTP at three different bar positions (low: above patella, mid: mid-thigh, high: crease of hip) while motion capture and GRF data were recorded. Inverse dynamics was used to calculate peak ankle, knee, and hip NJM. Joint angles at peak NJM were also extracted. Main effects for bar position existed for hip NJM and hip and knee joint angles. Pair-wise comparisons showed that hip NJM differed significantly between all positions. Strength and sports coaches should consider these results when they use the IMTP to assess and monitor maximal strength as part of their conditioning programs.

KEYWORDS: biomechanics, sports, IMTP, maximal strength, performance.

INTRODUCTION: The isometric midthigh pulls (IMTP) is a multi-joint isometric exercise that is used to measure an athlete's force-generating capacity (Brady, et al., 2020). IMTP performance is typically quantified with variables such as peak force production, rate of force development, impulse, and asymmetry, because these variables all have high reliability (within- and between-session) and provide information about an athlete's strength and explosiveness (Comfort, et al., 2015; Dos'Santos, et al., 2018; Haff, et al., 2015; Townsend, et al., 2019). Importantly, these variables also show strong relationship with dynamic performances, such as weightlifting, cycling and sprinting performance (Beckham, et al., 2013; Dos'Santos, Thomas, Comfort, et al., 2017; Townsend, et al., 2019; West, et al., 2011). Therefore, the IMTP provides a simple and safe assessment tool to assess strength, prescribe future training intervention, and monitor adaptations to training programs (Beckham, et al., 2018; Dos'Santos, Thomas, Jones, et al., 2017).

The IMTP is performed with the body positioned in a posture that matches the second pull of the clean, and with the bar located between the athlete's knee and hip joints (Brady, et al., 2020). Strength and conditioning coaches have used various postures and bar positioning according to an athlete's health history and anthropometries (Brady, et al., 2020). In addition, several studies showed that changing body posture and bar position affect joint angles and ground reaction forces during the IMTP (Beckham, et al., 2018; Guppy, et al., 2019). Given that changes in joint angles would also affect the maximum force-generating capacity of specific muscles (due to changes in length-tension relationship and internal moment arms), it is likely that the mechanical demands across joints also differ (Dos'Santos, Thomas, Jones, et al., 2017).

However, no previous study has identified the effects of bar position on an athlete's ability to produce NJMs at the ankle, knee, and hip joints during IMTP. Therefore, the purpose of this study was to identify the effect of bar positioning on the peak ankle, knee, and hip NJMs during the IMTP. The goal of this research is to understand the effect of bar position on the peak NJMs in the lower extremity during IMTP in order to provide better insight for strength and sport coaches about how to better use the IMTP in the assessment, prescription, and monitoring of maximal strength.

METHODS: Eight female NCAA Division I lacrosse athletes were recruited for this study (although data from one participant was removed because of bad data). Each player provided written informed consent, which was approved by the Marquette University's IRB. Data collection occurred after the end of the player's offseason training program, during which all players participated in a resistance training program that included dynamic and isometric exercises. All players were thus well familiar with the IMTP and IMTP test procedures.

Reflective markers were attached to various anatomical landmarks and marker clusters were attached to the thighs, shanks, and feet of both legs (Figure 1). Each player performed a standardized dynamic warm-up that consisted of simple callisthenic exercises and several submaximal and maximal jumping tasks.

For the IMTP testing, each player performed three repetitions of the IMTP at three different bar positions (low: above patella, mid: mid-thigh, and high: creases of hip) (Figure 1) in a random order. At each position, participants performed two submaximal IMTP efforts, which were then followed by the three maximal IMTP efforts. During each maximal effort players were instructed to pull on the bar as hard and as fast as possible and received verbal encouragement.

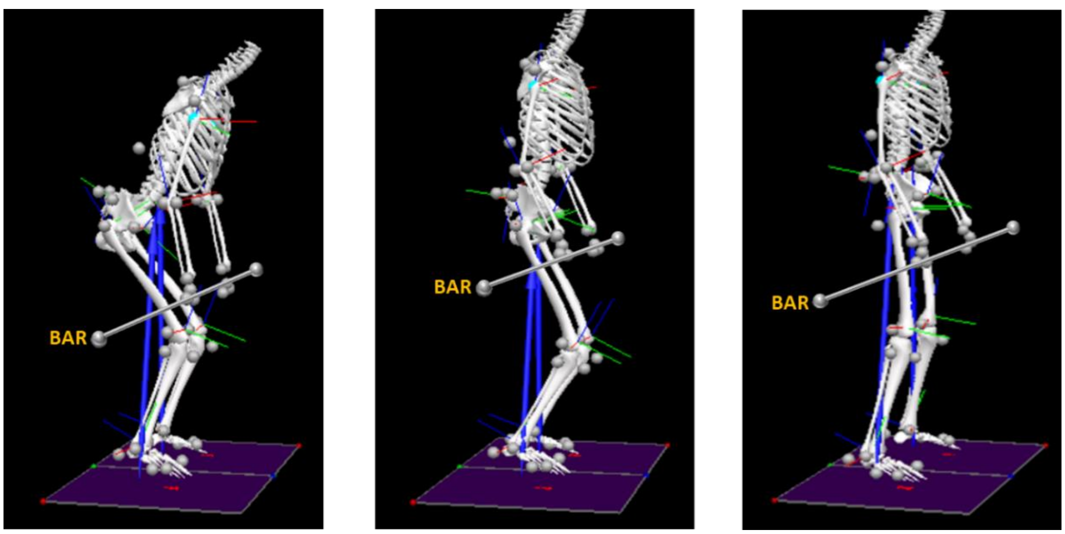

Figure1. Depiction of the Visual3D model at different bar positions during isometric mid-thigh pull, low: above patella (left), mid: at mid-thigh (middle), and high: crease of hip (right).

Kinematic data were collected with 14-camera motion capture system at 100Hz. Kinetic data were collected with two force plates at 1000Hz. A standard inverse dynamic analysis that combined kinematic, ground reaction force (GRF), and anthropometric data was used to calculate the net internal NJM at ankle, knee, and hip joint. The peak NJM and relevant joint angles at the ankle, knee, and hip during each maximal effort IMTP were extracted. NJM and joint angles from the right and left leg were averaged and normalized to body-mass (i.e., N·m/kg). The joint-averaged NJM and joint angles were then averaged across each repetition for each of the three positions and used for statistical analysis. Three separate one-way analyses of variance were performed to determine the effects of bar position on the NJM and relevant angles at the ankle, knee, and hip joints. The level of statistical significance was set to an α-level of 0.05. Post-hoc comparisons were made with Bonferroni corrections to the α-level (i.e., 0.05/3 = 0.017).

Result: For the NJM, significant main effects of bar position existed only for the hip joint (Table 1), where the respective post hoc comparisons showed that all pairwise comparison differed significantly from each other.
For the joint angles, significant main effects of bar position existed for all the knee and hip joint (Table 2). Post hoc comparisons indicated that differences at both joints were most pronounced when comparing low versus high bar position.

Table 1. Peak (mean ± SD) ankle, knee, and hip net joint moments (N·m/kg) during isometric mid-thigh pulls at the three different bar positions (Low, Mid, High) and the p-values for the associated analysis of variance (ANOVA) and post-hoc comparisons.

	Bar position			ANOVA	Post-Hoc Comparisons		
	Low	Mid	High		Low vs Mid	Low vs High	Mid vs High
Ankle	1.03±0.15	1.14±0.28	1.03±.031	0.658	-	-	-
Knee	0.65±0.11	0.97±0.41	0.59±0.34	0.076	-	-	-
Hip	2.64±0.41	1.24±0.27	0.73±0.26	0.001	0.001	0.001	0.025

Table 2. Ankle, knee, and hip joint angles (mean ± SD [°]) at the peak net joint moments during isometric mid-thigh pulls at the three different bar positions (Low, Mid, High) and the p-values for the associated analysis of variance (ANOVA) and post-hoc comparisons.

	Bar Position			ANOVA	Post-Hoc Comparisons		
	Low	Mid	High		Low vs Mid	Low vs High	Mid vs High
Ankle	12.3±7.3	13.6±10.0	9.6±6.9	0.650	-	-	-
Knee	47.6±10.6	36.7±8.1	21.6±10.0	0.001	-	0.001	0.026
Hip	66.6±7.4	35.8±8.4	25.3±8.6	0.001	0.001	0.001	-

DISCUSSION: The purpose of this study was to identify the effect of bar positioning on the peak ankle, knee, and hip NJM during the IMTP. The results showed that the positioning of the bar influenced peak hip NJM. Specifically, peak hip NJM were greatest when the bar was positioned just above the patella and were smallest when positioned in the crease of the hip joint.
Previous studies have also studied the effects of bar positioning and body posture on IMTP variables (Beckham, et al., 2018; Comfort, et al., 2015; Dos'Santos, Thomas, Jones, et al., 2017; Guppy, et al., 2019). For example, Guppy et al. (2019) investigated the effects of altering barbell position on GRF kinetics during the IMTP and found that an upright torso position and barbell position associated with the second pull position enabled the greatest force-generating capacity among 4 different testing positions. Similarly, Beckham et al. (2012) demonstrated significant effects of bar position (floor, knee, MTP, and lockout) on the peak GRF generated during deadlift (Beckham, et al., 2012). Our findings showed that peak hip NJM differed significantly with bar position, such that a lower bar position produced the greatest peak hip NJM and that an increase in bar height lead to a decrease in peak hip NJM. The lowest bar position was also associated with the greatest amount of hip flexion, which may subsequently influence the internal moment arm and the force-producing capacity of the hip extensor muscles. Therefore, the low position likely provides a more favorable posture that allows the hip extensor muscles to generate larger maximal forces and ultimately produce greater NJM during IMTP. It may be of interest to determine if training in a low bar position also strengthens the hip extensor muscles to a greater extent due to the increase in loading.
While knee flexion angles differed significantly between all bar positions, except for the low versus mid position, the peak NJM at the knee did not differ. It thus appears that any purported changes in internal moment arm and force-producing capacity of the hip extensor muscles did not occur to a notable extent at the knee. There were no significant effects of bar position on the peak ankle NJM and joint angles. It is interesting to briefly consider the lack of change in NJM at the ankle and knee with respect to the overall mechanical demands during the IMTP. More specifically, the decreasing role of the hip extensor muscles during IMTP with the bar in higher positions would

suggest that the use of the IMTP as a test of maximal strength in these positions primarily assesses the strength of the ankle plantarflexor and knee extensor muscles. Strength and sports coaches should therefore be aware that testing maximal strength with the bar at either mid-thigh or crease of the hip does not provide information about the maximal force-producing capacity of the hip extensor muscles. Future studies may wish to identify whether these differences have any implications on lower extremity NJM during dynamic performance.

CONCLUSION: The current study showed that bar position affects the NJM and angles of certain lower extremity joints. Specifically, a lower bar position allows for greater production of hip extensor NJM. Strength and sports coaches should consider these results when they use the IMTP to assess and monitor maximal strength as part of their conditioning programs.

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