EVALUATING THE INFLUENCE OF KNEE JOINT ANGLE ON MAXIMUM ISOMETRIC BELT SQUAT PERFORMANCE

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Belt squat testing measures maximum upward isometric force from the lower extremities using a ground-tethered belt around the waist. A lack of standardized body positioning during isometric belt squat testing can lead to inconsistent test results. We aimed to evaluate the influence of sagittal knee joint angles on maximum isometric belt squat performance. Thirty-three healthy volunteers (24 female) performed one maximal effort belt squat at five randomly ordered sagittal knee joint angle ranges: (1) 80-100°, (2) 100-120°, (3) 120-140°, (4) 140-160°, and (5) 160-180°. Sagittal knee joint angles between 120-140° and 140-160° led to greater maximum vertical ground reaction forces compared to each other condition ($p \leq 0.017$). Our results provide a starting point to establish best-practices for assessing lower limb strength during maximum isometric belt squat testing.

KEY WORDS: force, lower extremity, strength

INTRODUCTION: Lower extremity strength testing is common in athletic and performance settings during training. Traditional concentric squat lifts are often used to assess lower limb muscle strength based on the total amount of weight an individual can lift. Typical back and front squat variations are considered safe exercises but need to be controlled for spinal and upper body loading (Hartmann et al., 2013; Chandler and Stone, 1991). Maximum voluntary isometric tests provide a standardized method for assessing total joint or limb strength. The maximum isometric mid-thigh pull is a common performance test for strength and rate of force development (Comfort et al., 2019). During this test, an individual produces maximal upward isometric force by pulling upward on a fixed bar set at the midline of the thigh, with their feet on the ground, which resembles the second pull phase of a clean and jerk Olympic lift. Upper body strength and lack of familiarity with this lifting position can limit the assessment of lower limb strength. As a performance testing measure, the belt squat may offer an alternative that is more representative of true lower extremity force production compared to other closed chain isometric tests that may be limited by upper extremity or spinal loading factors. During belt squat testing, an individual wears a belt that is fixed to an immovable surface by a chain or cable that is instrumented with a force gauge or while standing on force plates. Studies looking at lower limb muscular activations and kinetic differences between the belt squat and back squat have found that while musculoskeletal loading may be similar or slightly greater during the belt squat, lower back and spinal loads were reduced during belt squat testing (Evans et al., 2019; Layer et al., 2018).

The purpose of our study was to evaluate the influence of sagittal knee joint angles on peak vertical force production during maximum isometric belt squat testing to establish best practices for assessing lower limb strength. We measured vertical ground reaction forces during maximum isometric belt squat testing in five different sagittal knee joint angle range conditions: (1) 80-100 degrees, (2) 100-120 degrees, (3) 120-140 degrees, (4) 140-160 degrees, and (5) 160-180 degrees. Because peak force production has been achieved at hip joint angles of 145-degree and knee joint angles of 125-degrees during the maximum isometric mid-thigh pull testing (Beckham et al., 2018), we hypothesized that sagittal knee joint angles between 120-140 degrees would allow participants to produce the greatest vertical ground reaction forces during maximum isometric belt squat testing.

METHODS: Thirty-three healthy, active collegiate volunteers, free from lower extremity injuries, participated in this study. Participants included nine males (age 24.11 ± 3.44 years; height 1.76 ± 0.10 m; mass 88.10 ± 16.24 kg) and twenty-four females (age 23.42 ± 3.84 years; height 1.66 ± 0.08 m; mass 67.32 ± 12.38 kg) who actively participated in at least 30 minutes of exercise three times per week. Institutional Review Board approved informed consent was obtained for each participant prior to participation.

Figure 1: Belt squat platform set up and participant

We measured vertical ground reaction forces separately for the left and right lower limbs using two 40 x 60cm AMTI force plates sampling at 1000Hz. A custom Sorinex rack with a centered eye bolt and Spud belt was used for maximum isometric belt squat testing (**Figure 1**). Total maximum vertical ground reaction forces, minus bodyweight, were calculated by summing vertical ground reaction forces from each force plate. Ground reaction forces were low-pass filtered using a fourth-order Butterworth filter at 100 Hz cutoff frequency.

Prior to data collection, we identified five chain lengths to achieve five target sagittal knee joint angle ranges for each participant while standing on the force plates. The same researcher measured sagittal knee joint angles during each squatting position for all trials using an angle goniometer aligned with the long axis of the thigh and shank segments in the sagittal plane. We instructed participants to maintain a neutral head position, facing forward with hands clasped in front of the chest, feet hip distance apart, and the foot arch (sagittal plane) aligned with the eyebolt midway between the force plates (frontal plane). Each participant completed a researcher-led dynamic warm-up and two isometric belt squat practice trials for 3-seconds at 75% and 90% effort, respectively.

Following practice trials, we zeroed the recording equipment and recorded participant bodyweight during quiet standing on the force plates. Next, we attached the chain between the belt and ground-fixed eyebolt corresponding to the premeasured knee joint angle condition. Each participant completed one, five-second, maximal effort isometric belt squat in each knee joint angle condition. Condition order was randomized and sagittal knee joint angles were remeasured prior to each test. Participants were provided with two-minutes rest between each maximum isometric belt squat test.

We calculated descriptive and inferential statistics using JMP (JMP Statistical Discovery LLC). To assess differences among knee joint angle conditions, we performed a one-way analysis of variance (ANOVA), comparing maximum vertical ground reaction force values among knee joint angle conditions (α = 0.05). We used Tukey-Kramer HSD pairwise comparisons to evaluate differences between each condition.

RESULTS: Mean (± standard deviation) sagittal knee joint angles in each condition included: (1) 80-100°: 94.51° ± 3.25°, (2) 100-120°: 112.09° ± 4.25°, (3) 120:140°: 128.79° ± 4.39°, (4) 140-160°: 148.89° ± 4.77°, and (5) 160-180°: 168.79° ± 4.96°. Maximum vertical ground reaction force values were normally distributed (Shapiro-Wilk test of normality, p > 0.05). One-way ANOVA test results identified statistically significant differences among knee joint angle conditions ($F(4) = 15.2$, η_p^2 = 0.22, $p < 0.001$; **Figure 2, left**). Tukey-Kramer HSD testing identified that knee joint angles between 120-140 degrees and 140-160 degrees led to significantly greater maximum vertical ground reaction forces compared to 80-100 degrees (p < 0.001), 100-120 degrees (p < 0.017), and 160-180 degrees (p < 0.001). No other conditions showed statistically significant differences. Normalized to body mass, relative maximum vertical ground reaction force values were normally distributed (Shapiro-Wilk test of normality, p > 0.05). One-way ANOVA test results identified statistically significant differences among knee joint angle conditions ($F(4) = 24.8$, $\eta_p^2 = 0.38$, p < 0.001; **Figure 2, right**). Tukey-Kramer HSD testing identified that knee joint angles between 120-140 degrees and 140-160 degrees led to greater relative maximum vertical ground reaction forces compared to knee joint angles between 80-100 degrees (p < 0.001), 100-120 degrees (p = 0.0023), and 160-180 degrees (p < 0.001). Relative maximum vertical ground reaction force values at knee joint angles between 100-120 degrees exceeded 80-100 degrees (p < 0.0043).

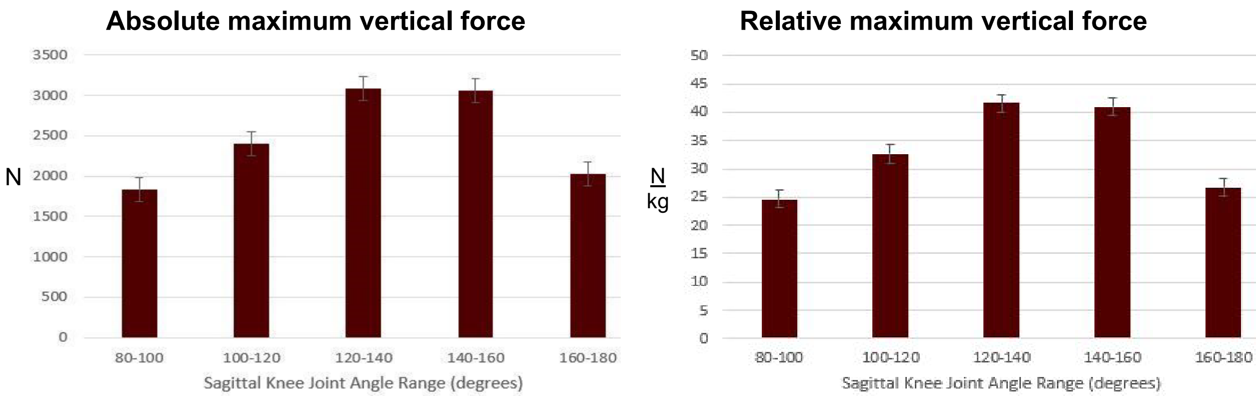

Figure 2: Mean (± standard error) isometric belt squat (Left) absolute maximum total vertical forces during each sagittal knee joint angle range and (Right) relative maximum total vertical forces during each sagittal knee joint angle range, scaled to body mass.

DISCUSSION: During maximum isometric belt squat testing, participants produced greater total absolute and relative vertical forces when sagittal knee joint angles were between 120 and 160 degrees, compared to knee joint angles between 80-120 degrees or 160-180 degrees. We partially confirmed our hypothesis that peak vertical forces would be produced when sagittal knee joint angles were between 120 to 140 degrees during maximum isometric belt squat testing. In comparison to previous lower body isometric strength test studies, we identified greater maximum vertical force production across a wider range of knee joint angles. During maximum isometric mid-thigh pull testing, knee joint angles have been set at 125-degrees (Beckham et al., 2018), and during isometric back squat and isometric belt squat testing, thigh segment angles have been set at 45-degrees (Layer et. al, 2018). Sagittal knee joint angles set at 90-degrees have also shown greater electrical muscle activation during maximal isometric back squat testing, compared to 20 and 140-degrees (Marchetti et al., 2016). In our study, greater maximum vertical force production throughout a broader range of sagittal knee joint angles during isometric belt squat testing could be attributed to differences in muscle fiber recruitment while producing equivalent external forces (Wakeling et al., 2012) and performance variability among participants (Armstrong et al., 2022).

Prior research has highlighted the importance of the hip joint angle during isometric mid-thigh pull testing, identifying that a hip joint angle of 145 degrees has led to greater force production (Dos'Santos et al., 2017). Here, we did not measure sagittal hip joint angles because the belt obstructed the view of the joint center on most participants, which prohibited accurate measurement. Because trunk posture during the mid-thigh pull resembles the second pull phase of a clean and jerk Olympic lift, the trunk is more upright compared to the belt squat. In order for the belt to fit snugly on the body and to maintain stability, a forward trunk lean is required during the belt squat, resembling a more traditional squatting posture (Layer et al. 2018, Wretenberg et al., 1996). We could therefore expect reduced hip joint angles during the belt squat compared to the midthigh pull.

There are limitations in our study. Our sample included more female than male participants (24 female vs. 9 male). Future studies with larger sample sizes could evaluate sex differences during lower body isometric belt squat testing. Participants in our study completed a single maximal isometric belt squat test in each sagittal knee joint angle range. Analyzing multiple trials will allow test-reliability to be assessed and compared among lower body isometric strength tests. Kinematic motion capture could have improved the accuracy of our sagittal knee joint angle measurements.

CONCLUSION: By adjusting sagittal knee joint angles during maximum isometric belt squat testing, we identified two knee joint angle ranges that produced greater peak vertical ground reaction forces (120-140 degrees and 140-160 degrees). This preliminary research provides starting point for standardizing maximum isometric belt squat testing, which is applicable to researchers and practitioners interested in assessing lower extremity strength. Future investigations should consider evaluating the test-retest reliability and force production during isometric belt squat testing compared to the commonly used isometric mid-thigh pull. Establishing standardized lower extremity joint angles and body positioning during isometric strength testing can improve measurement reliability, comparisons among studies, and help to inform applications for isometric test variations.

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