# EFFECTS OF ANTERIOR-POSTERIOR LOAD PLACEMENTS IMPOSED BY A TRANSFORMER BAR ON SQUAT BIOMECHANICS

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Examining the effect of anterior-posterior load placements imposed by a transformer bar could provide additional options for squatting exercises. The purpose of this study was to quantify trunk and pelvis angles and low back and lower extremity joint moments among the regular back and front squats and four squats with a transformer bar. Twelve males and 12 females performed six different squatting variations with a load of 70% of their one-repetition maximum of the regular front squat: back and front squats with a regular bar, back and front squats with a transformer bar, and squats with more anterior or posterior loads with a transformer bar. Joint angles and moments were extracted at the thigh angle of 70° in the ascending phases, corresponding to a posture close to a parallel squat. Trunk flexion angles were the highest for the transformer bar back squat and transformer bar posterior load squat. The greatest pelvis flexion angles were observed for the regular back squat, transformer bar back squat, and transformer bar posterior load squat. Low back joint moments were the highest for the transformer bar anterior load squat. Hip joint moments were significantly lower for the regular bar front squat compared to the other squat conditions. More posterior load placements resulted in decreased low back moments, increased trunk and pelvis flexion angles, and similar hip and knee moments compared to more anterior load placements. Changing the load placement does not affect low back and lower extremity loading as expected because the trunk and pelvis angles could be adjusted according to load placements. An anterior load placement may result in greater low back moments while a posterior load placement has greater trunk and pelvis flexion, which should be taken into consideration for people with low back impairments.

**KEYWORDS:** Strength training; Kinetics; Low back; Lower extremities; Injury

**INTRODUCTION:** Resistance training, when performed appropriately, may induce many health benefits, including increased muscle strength, improved cardiovascular function, higher bone mineral densities, decreased risk of falling, better sports performance, etc (Fragala et al., 2019; Lloyd et al., 2016). One frequently used exercise for lower body strength training is the squat. Squats not only provide a convenient way for training, but also allow a greater transfer of strength gain to other activities with a similar standing posture (Wilson, Murphy, & Walshe, 1996). Previous studies have extensively examined the effects of load magnitudes, squat depths, and squat techniques on lower extremity and low back loading during squats to identify the optimal training strategy for each joint while minimizing injury risk (Cotter, Chaudhari, Jamison, & Devor, 2013; Hartmann, Wirth, & Klusemann, 2013).

The two most common forms of squats are the back and front squats. In the back squat, the bar is placed across the shoulders on the upper trapezius with abducted shoulders and flexed elbows for bar stabilization. In the front squat, the bar sits on the front of the deltoids with flexed shoulders and elbows to stabilize the bar. While both squats mainly target lower extremity and trunk extensors, the different load placements in the anterior-posterior direction raise interests from researchers to examine their biomechanical differences. However, inconsistent findings have been observed for the differences in muscle activation and joint moments between the back and front squats (Gullett, Tillman, Gutierrez, & Chow, 2009; Korak, Paquette, Fuller, Caputo, & Coons, 2018; Yavuz, Erdag, Amca, & Aritan, 2015). These discrepancies could be due to different testing populations and load magnitudes. Another possible explanation is the relatively small difference in load placement between the back and front squats, allowing participants to make minor adjustments to their postures to impose similar external loading to

their low back and lower extremities. The effects of a more anteriorly or posteriorly positioned load on squat biomechanics, however, are still unknown.
A recently developed transformer bar has been advocated by its manufacturer for mimicking different squatting variations, such as back and front squats, due to adjustments allowing various load placements. Additionally, it has two front handles that allow bar stabilization with shoulders closer to the neutral position, requiring less shoulder mobility and upper extremity involvements. Examining the effect of load placements imposed by a transformer bar could provide additional options for squat exercises that emphasize training specific joints while minimizing injury risk. In addition, identifying the biomechanics of squats with a transformer bar could reveal potential strategies for rehabilitation purposes and accommodation of individuals with upper extremity limitations or injuries.
The purpose of this study was to quantify trunk and pelvis angles and low back and lower extremity joint moments among the regular back and front squats and four squats with different anterior-posterior load placements imposed by a transformer bar. Based on the mechanical relationships between the load and different joints, it was hypothesized that a more anteriorly located load would result in greater low back and hip moments but less knee moments.

**METHODS:** Twelve males and 12 females participated (age: 21.8 ± 2.4 years; height: 1.74 ± 0.10 m; mass: 72.0 ± 11.8 kg). Participants had experience performing regular back and front squats for a minimum of 6 months and had been performing strength training at least two times per week for a total of at least 2 hours per week at the time of testing. Participants did not have any lower extremity or spinal surgeries or an injury that kept them from participating in physical activity for more than two weeks in the previous six months. This study was approved by the University of Wyoming Institutional Review Board. Participants signed informed consent forms.
The study consisted of two sessions that were performed 3-10 days apart. In the first session, participants performed the one-repetition maximum front squat progression with a conventional bar. In the second session, retroreflective markers were placed on the trunk and lower extremities as well as on the bar. Kinematic data were recorded using eight Vicon Bonita 10 cameras at a sampling frequency of 160 Hz. Ground reaction forces (GRF) were captured using two Bertec FP4060 force platforms at a sampling frequency of 1,600 Hz.
Participants performed six different squatting variations: back (Figure 1) and front (Figure 2) squats with a regular bar, back (Figure 3) and front (Figure 4) squats with a transformer bar, and squats with more posterior (Figure 5) or anterior loads (Figure 6) with a transformer bar. The settings for the transformer bar were as recommended by its manufacturer, including 2.5 C for the front squat, 1D for the back squat, 3A for the anterior load squat similar to kettlebell squats, and 1A for the posterior load squat similar to cambered squats (https://store.kabukistrength.net/products/transformer-bar).
Participants started with heels hip-width apart and performed all squats with 70% of their one-repetition maximum of the regular front squat. An elastic band was placed at the individual's parallel squat point, and they were instructed to touch the band at the bottom of the squat. For each squat, participants were instructed to keep their trunks as straight as possible. For squats using the transformer bar, participants were directed to keep their upper arms in line with their torso to make sure participants did not significantly shift the weight of the bar with the handles. Additionally, participants were instructed to take about two seconds for the descending phase and another two seconds for the ascending phase guided by a metronome. Participants performed one practice trial and two official trails for each squatting variation with a minimum of a 1-minute break between two trials. The order of the six squat conditions was randomized.
Three-dimensional knee, hip, and low back moments were calculated through a bottom-up inverse dynamics approach (Layer et al., 2018). Trunk flexion angles were calculated as the angle between the upper trunk and the vertical axis in the sagittal plane (Figure 7). Pelvis flexion angles were calculated as the angle between the pelvis and the vertical axis in the sagittal plane (Figure 7). Thigh flexion angles were calculated as the angle between the thigh and the vertical axis in the sagittal plane (Figure 7). To control the effect of squat depth on kinematic and kinetic variables, trunk flexion angles, pelvis flexion angles, and knee, hip, and low back moments were extracted when the thigh angle was at 70° in the ascending phases,

corresponding to a posture close to a parallel squat (Figure 7). For participants who did not achieve 70° of thigh angle during certain conditions of squats, the least peak thigh angle among all conditions was utilized as the critical angle for extracting dependent variables. Knee and hip moments and thigh angles were averaged between the left and right sides. The averages of the two official trials were analyzed using repeated-measures analyses of variance (ANOVA), followed by paired t-tests (p<0.05 for statistical significance).


Figure 1. Regular back squat

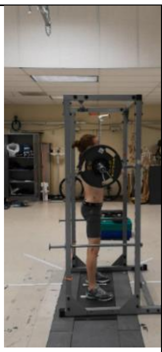
Figure 2. Regular front squat

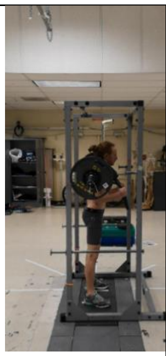
Figure 3. Transformer bar back squat


Figure 4. Transformer bar front squat


Figure 5. Transformer bar posterior load squat


Figure 6. Transformer bar anterior load squat


Figure 7. Segment angles

**RESULTS:** Trunk flexion angles were the highest for the transformer bar back squat and posterior load squat. The greatest pelvis flexion angles were observed for the regular back squat, transformer bar back squat and posterior load squat. Low back moments were the highest for the anterior load squat and the second highest for the regular front squat and transformer bar front squat. Hip moments were significantly lower for the regular bar front squat compared to other squat conditions. Knee moments were similar among all squat conditions.

Table 1. Means (standard deviations) of dependent variables for different squat conditions and p values of analyses of variance

| | Regular Bar Back Squat | Regular Bar Front Squat | Transformer Bar Back Squat | Transformer Bar Front Squat | Transformer Bar Posterior Load Squat | Transformer Bar Anterior Load Squat | P values of ANOVA |
|---|---|---|---|---|---|---|---|
| Trunk Flexion Angle (°) | 38.0 ± 5.8 BC | 39.7 ± 5.8 B | 48.0 ± 6.8 A | 39.0 ± 7.4 B | 47.8± 6.0 A | 35.7 ± 6.8 C | **<0.001** |
| Pelvis Flexion (+) / Extension (-) Angle (°) | 7.0 ± 8.2 A | -1.6 ± 7.4 C | 6.7 ± 7.8 A | 1.82± 8.0 B | 7.5 ± 7.9 A | -1.1± 7.6 C | **<0.001** |
| Low Back Moment (Nm/BW/BH) | 0.16 ± 0.02 C | 0.17 ± 0.03 B | 0.16 ± 0.03 C | 0.17 ± 0.03 B | 0.16± 0.03 C | 0.18 ± 0.03 A | **<0.001** |
| Hip Moment (Nm/BW/BH) | 0.10 ± 0.01 A | 0.09± 0.01 B | 0.10± 0.02 A | 0.10 ± 0.01 A | 0.10 ± 0.02 A | 0.10 ± 0.02 A | **<0.001** |
| Knee Moment (Nm/BW/BH) | -0.07 ± 0.01 A | -0.07 ± 0.01 A | -0.07± 0.01 A | -0.07 ± 0.01 A | -0.072± 0.02 A | -0.07 ± 0.02 A | 0.066 |

Note: BW: body weight; BH: body height; The effect of squat conditions on each dependent variable was grouped, where A>B>C.

**DISCUSSION:** The hypothesis related to load placements and low back moments was supported. Low back moments were the highest for the transformer bar anterior load squat, which had the most anterior load placement. In addition, the low back moments for two front squats with a regular bar and a transformer bar were greater than the other squats with more posteriorly located loads. Participants compensated the anterior location of the load by decreasing their trunk flexion, as participants demonstrated the least trunk flexion for the squats with anterior load placements. However, it appeared that this decrease in trunk flexion did not completely offset the increase in the load placement in the anterior direction, resulting in increased low back moments.

The hypothesis related to load placement and knee and hip moments was not supported. Similar hip and knee moments were found among all the squat conditions, except for the regular bar front squat. Theoretically, with the same body posture, the more anteriorly located load will increase the external moment arms from the load to the low back and hip joints and decrease the moment arms to the knee joint. However, it appeared that with the transformer bar, independent of the load placement, participants adjusted their trunk and pelvis angles so that the weight vector of the load and their upper body would pass through a similar point between the hip and knee joints as the regular bar squat. When the load was placed anteriorly with a transformer bar, participants compensated with decreased trunk flexion as well as decreased pelvis flexion or even pelvis extension. This compensation was enough to offset the anterior placement of the load and resulted in similar hip and knee moments. In summary, participants utilized a generalized motor control pattern when a transformer bar was used. This control strategy was to keep lower extremity moments demands similar to a regular bar back squat through changing trunk and pelvis flexion angles. However, the current report was limited to the body posture that was close to a parallel squat in the ascending phase. Future analyses should compare these squatting variations across a greater joint range of motion.

**CONCLUSION:** At the body posture close to a parallel squat, more posterior load placements imposed by a transformer bar resulted in decreased low back moments, increased trunk and pelvis flexion angles, and similar hip and knee moments compared to squats with more anterior load placements. Changing the weight placement does not affect low back and lower extremity moments as people may have expected because the trunk and pelvis angles could be adjusted according to load placements. A more anterior placement of the load may result in greater low back moments while a more posterior load placement has greater trunk flexion, which should be taken into consideration for people with low back impairments.

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