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A Biomechanical Analysis of the Effects of Bouncing the Barbell in the Conventional Deadlift

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Abstract: The purpose of this study is to analyze biomechanical differences between the bounce and pause styles of deadlifting. Twenty physically active males performed deadlifts at their 75% one repetition maximum testing utilizing both pause and bounce techniques in a within-subjects randomized study design. The average peak height the barbell attained from the three bounce style repetitions was used to compute a compatible phase for analysis of the pause style repetitions. Net joint moment impulse (NJMI), work, average vertical ground reaction force (vGRF), vGRF impulse and phase time were computed for two phases, lift off to peak barbell height and the entire ascent. Additionally, the ankle, knee, hip, and trunk angles at the location of peak barbell height. During the lift off to peak barbell height phase, although each of the joints demonstrated significantly less NJMI and work during the bounce style, the hip joint was impacted the most. The average vGRF was greater for the bounce however the vGRF impulse was greater for the pause. The NJMI results for the ascent phase were similar to the lift off to peak barbell height phase, while work was significantly less for the bounce condition compared to the pause condition across all three joints. Strength and conditioning specialists utilizing the deadlift should be aware that the bounce technique does not allow the athlete to develop maximal force production in the early portion of the lift. Further analyses should focus on joint angles and potential vulnerability to injury when the barbell momentum generated from the bounce is lost.

Key Words: Work, Moment, Impulse, Joint, Force, GRF

INTRODUCTION

A thorough understanding of the biomechanical characteristics of different exercises will optimize the strength and conditioning professional's program designing capabilities and maximize physical adaptations in their athletes/clientele. The deadlift exercise is a staple of many strength and conditioning programs regardless of the individual/athletes' goals. The deadlift is a multi-joint exercise predominantly relying on the posterior and knee extensor musculature to be executed (10). Because the lift can be performed with heavy loads, a large mechanical stimulus is placed on the body yielding greater strength and power adaptations(29). Furthermore, the center of mass location of the weighted barbell remains anterior to the lifter's center of mass, which creates greater demand for the erector spinae muscles to stabilize the spine when compared to the back squat (2, 4, 6, 19, 23). While simple observation of the deadlift suggests it just involves picking up a load from the floor, competent completion of the deadlift is a complex task because of the number of joints and muscles involved to activate in a specific synchronized pattern. The joints involved in the concentric phase of the deadlift involve the ankle, knee, and hip and sacral (trunk) joints moving into extension(2, 6, 14, 19). However when performed correctly there should be little movement between the sacrum and the trunk in order to keep a neutral spine and reduce spinal excursion, providing greater stiffness to stabilize the lumbar spine (5, 8, 18) and mitigate shear, flexion and torsional forces directly experienced by the intervertebral disc which could lead to injury (11, 18, 20). Likewise, the spine maintains an optimal position to enhance the effectiveness of the gluteus maximus as the prime mover rather than the erector spinae muscles(2, 10, 12, 13).

Additionally, although the ankle joint does not move into full extension (plantarflexion) as seen with Olympic lifts, the magnitude of ankle extension and the ankle extensor muscle contribution are dependent on skill level and anthropometrics(2, 6, 19). Throughout the entire concentric portion of the deadlift, the hip is the dominant contributor to achieve vertical bar displacement(2, 6, 19). Unlike the squat which is a continuous movement, the deadlift has three distinct phases; liftoff, knee-pass and lockout(2, 6, 19). The liftoff begins with the barbell leaving the floor with the knee extensors make a larger contribution than they do in the latter two phases(2, 6, 19). The knee-pass phase relies on relatively equal contributions from both the knee and hip extensors(2, 6, 19). Lastly, the lockout phase of the lift is accomplished largely by the hip extensors, with little to no help from the knee extensors because the knees are fully extended(2, 6, 19).

There are several variations of the deadlift; conventional, sumo and hex bar/trap bar. The conventional deadlift is most commonly used and requires a shoulder width stance with the hands placed outside the legs(2, 6, 14, 19, 23). Many strength coaches favor the conventional deadlift over the sumo and hex bar variation when developing the posterior chain for several reasons; less adductor and gracilis muscle flexibility required because the feet are closer together (9), more mechanical and physiological work performed (3, 9), no need for special equipment (ie, hex bar) (4, 23, 24), greater lumbar extension/core development(6, 9, 10) and directly analogous to Olympic lifts and sporting movements such as jumping (14, 16, 29).

While biomechanical comparisons of the three deadlift variations have been thoroughly investigated, biomechanical comparisons of different lifting styles within each deadlift variation have not been studied. The two most frequently used lifting styles for the conventional deadlift include pausing and bouncing. Pausing requires allowing the barbell to come to a complete stop on the floor before initiation of the next repetition. Bouncing allows the load to bounce off the floor in between each repetition and is characterized by little to no eccentric control at the terminal end of the eccentric phase. Novice to high level lifters, those performing higher repetition sets, and athletes performing a set of deadlifts for time can be often be observed relying on the bouncing style to complete the set with a particular load.

The prevalence of different lifting styles and paucity of research investigating them for the deadlift demands the answers to various questions. Is one style more advantageous for yielding physical adaption? What implications does each style have on movement patterns of the conventional deadlift? Does the performance of a certain style portend greater risk of injury? The purpose of this study is to compare ankle, knee, hip kinematic and kinetic variables of the two deadlift styles during the liftoff and total ascent phase to elucidate biomechanical differences. Due to the ballistic nature of a bouncing style deadlift, under high load intensities we believe that mechanical work will be reduced and the lifter will have an altered movement pattern.

METHODS

Experimental Approach to the Problem

Multiple research studies have compared the conventional, sumo and hex bar deadlift to one another(2, 6, 19, 23). Studies have examined the deadlift in response to wearing a lumbar support belt and unstable surfaces, but there is a scarcity of research completed comparing different lifting techniques within a single variation(1, 7, 15, 24). The conventional deadlift is the most commonly used variation of the deadlift. Several styles are commonly used when performing the conventional deadlift; dynamic, countermovement, pause, bounce and touch and go(1, 24). In local gyms the most commonly observed techniques are the bounce and pause styles. By examining the joint kinetics in terms of net joint moment impulse (NJMI) and total work, as well as average vertical ground reaction force and impulse, the mechanical stimulus provided by different styles was compared. Lastly, a subjective measure like RPE could indicate a preferred method due to perceived difficulty.

Subjects

Twenty physically active men with a minimum of one-year deadlift experience volunteered to participate in this study (Table 1). No monetary compensation was provided for participants. Participants were excluded if they were unable to deadlift 62 kilograms for one repetition. Additionally, participants were excluded if they had currently or recently (past 6 months) experienced musculoskeletal pain or injury.

The university's institutional review board approved the procedures for this study. All participants were informed of the protocol and risks of testing and signed an informed consent document prior to participation.

(Table 1 here)

Procedures

Study procedures consisted of two sessions. The first session's purpose was to determine the raw (without use of assistive lifting gear) one repetition maximum (1RM) of the conventional deadlift of the participant. All participants began the testing with a standardized warm up consisting of 5 minutes on the elliptical, two body weight movements focusing on gluteus complex activation, one body weight movement focused on thoracic mobility and any other movement desired by the participant necessary for optimal readiness. Participants' one repetition maximum (1RM) were then obtained utilizing the National Strength and Conditioning Association (NSCA) 1RM protocol. Participants were not allowed shoes (barefoot), weight belt or lifting straps, only chalk was allowed. Stance width (as long as within hand grip distance) and handgrip were self-selected by the participant. One-repetition maximums were considered successful when the participant moved the weight in one continuous motion with no cessation of movement until the knees and hips were fully extended and they returned with the weight to the floor under control (did not drop weight). After obtainment of 1RM, participants were familiarized with the two different lifting styles and allowed to practice the movements with submaximal loads (less than 50% of their 1RM).

A minimum of 4 days was required between the 1RM establishment and data collection for the two lifting styles. Participants were asked to avoid lower body exercise during the 4-day rest period.

All participants began the second session with the same standardized warm up protocol from session one. Data collection performed on a wooden platform using Olympic style bumper plates (Dynamic-Eleiko, Tacoma, Washington). Participants used 75% of their 1RM for data collection. Two sets of 5 conventional deadlift repetitions using 75% of their 1RM were performed using each lifting style; bounce and pause. The order of lifting conditions was randomized for each subject. Before each condition, instructions were given how to perform the movements. Pause condition instructions included allowing the bar to rest on the platform and come to a stop without letting go before performing the next repetition. Subjects were allowed to dictate their own velocity of eccentric movement in this condition. Bounce condition instructions included allowing gravity to pull the barbell down quickly and immediately performing the concentric portion of the lift upon contact with the floor. Also, participants were instructed not to physically push the bar downward into the platform. Upon completion of the trial the participant immediately reported rated perceived exertion (RPE) according to the Borg 10 point scale. All participants were instructed to rate RPE based off physical exertion and not pain as per guidelines for the Borg RPE scale. Participants were given a minimum of two minutes rest between each trial but allowed up to five minutes rest if needed.

Data Collection and Reduction

Three-dimensional participant and barbell kinematic data was collected via 12 Vicon infrared cameras, (Vicon, Oxford, UK), sampling at 100fps. All camera data was streamed into The Motion Monitor software (IST, Chicago, IL) where it was synchronized with ground reaction force data (1000Hz) from two force plates (AMTI, Watertown, MA). The force plates were secured independent of the surrounding platform to avoid barbell impacts inducing noise into the ground reaction force signals. A total of 35 reflective markers divided into 10 clusters were used to capture kinematic data of the subject and barbell. Two custom-made marker cluster inserts were used on the lateral portion of the bar collars. Participant marker clusters were placed on the calcaneus, 7.5cm below lateral tibial condyle for the shank, 12.5cm above the lateral epicondyle for the thigh, at spinous process of third thoracic vertebrae for the thorax, and the pelvis was tracked with a cluster of markers on each of the PSIS, greater trochanter of the left leg and 2.5cm below the greater trochanter on right leg. During participant setup and calibration, the proximal and distal ends of each body segment and the barbell center were digitized using a marker cluster attached to a calibrated stylus. Additionally, the ankle, and knee joint centers were calculated by taking midpoints between contralateral points at each respective joint using the stylus. The hip joint center was established using a series of eight points along a circumduction cycle for each hip to estimate the apex of femoral motion. Participant's mass and height were also recorded for anthropometric calculations required for locating each segment's center of mass using the Dempster parameters as reported by Winter(27).

Ankle, knee, hip and trunk joint angles and ankle, knee and hip net joint moments and power were computed using The Motion Monitor after zero-phase lag Butterworth filters were applied to the kinematic (10 Hz cutoff) and ground reaction force (35Hz cutoff) data. These data, along with the vertical ground reaction forces were exported as text files and further reduced using MatLab based scripts (The Mathworks, Inc., Natick, MA). The data from repetitions three, four and five were used for data analysis for each lifting strategy set unless one of them was deemed unusable, such as marker occlusion, in which case, repetition two was substituted. For both the ankle and hip kinematic and kinetic data, the polarity of the data were reversed so that extension and net joint extensor moments would be positive, thereby matching the knee. Lift off and the end of the ascent phase were defined when the vertical velocity of the barbell exceeded (lift off) and went below .05m/s. The local minima in the velocity curve defined the location of the peak height the barbell achieved after the bounce. The bounce style trials were analyzed first to determine the location and height the barbell attained following the bounce (Figure 1). The average peak height the barbell attained from the three bounce style repetitions was used to compute a compatible phase for analysis of the pause style repetitions. Net joint moment impulse (NJMI), work (integration of joint power data), average vertical ground reaction force (vGRF), vGRF impulse and phase time were computed for two phases, lift off to peak barbell height and the entire ascent. Additionally, the ankle, knee, hip, and trunk angles at the location of peak barbell height were computed.

(Figure 1 here)

Statistical Analysis

Following computation of the averages across the three trials for each dependent variable, exploratory data analysis was conducted on all dependent variables to examine normality and variability. For the NJMI and joint work during the lift off to peak barbell bounce height and ascent phases, separate two factor (joint by style) repeated measures analysis of variance (RMANOVA) were conducted. In circumstances where sphericity was violated, Huynh-Feldt degrees of freedom adjustments were used. Significant joint by style interactions were examined by conducting Bonferroni adjusted pairwise style comparisons between the two styles, as well as complex comparisons of the pause-bounce style differences between the three joints. Similarly, a two factor (joint by style) RMANOVA was conducted on the joint angles at the instant of peak barbell bounce height. Additionally, for peak barbell bounce height and ascent phases, paired t tests were conducted between the two styles for average vGRF, vGRF impulse and phase time. Finally, a paired t test was conducted between the two styles for RPE. To assist with applied meaningfulness of differences identified during post hoc testing, d family effect sizes using the Hedge's g approach for dependent samples and percent differences were computed. Interpretation of the effect sizes were made according to the convention suggested by Rhea (21). Statistical significance was considered at α=.05.

RESULTS

Four participants performed the lifts under both condition in a more extended knee position with a concurrent increase in hip and trunk flexion. This resulted in a net flexor moment during both periods of interest. These lifters were excluded from the NJMI and work statistical analysis. Descriptive statistics for all outcome measures are provided in Table 2.

(Table 2 here)

Lift Off to Peak Barbell Bounce Height

The deadlift styles had different effects on the ankle, knee and hip joint NJMI ($F_{1.5,21.4}$=43.7, P<.001, η^2_p=.757). Post hoc comparisons yielded significantly greater NJMI impulse for the pause style compared to the bounce style for the ankle (P<.001, d=1.58, $\%_{diff}$=70.0%), knee (P=.018, d=.73, $\%_{diff}$=73.6%) and hip (P<.001, d=2.22, $\%_{diff}$=84.1%) joints. Complex comparisons of the pause-bounce style differences revealed the hip difference to be significantly greater than the knee (P<.001, d=2.53) and ankle (P<.001, d=1.94). The difference between the pause and bounce styles for the ankle and knee were statistically equal (P=.067, d=.83).

Similarly, the deadlift styles had different effects on the ankle, knee and hip joint work ($F_{2,34}$=8.4, P=.001, η^2_p=.331). Post hoc comparisons yielded significantly greater work for the pause style compared to the bounce style for the ankle (P<.001, d=1.25, $\%_{diff}$=84.1%), knee (P=.023, d=.69, $\%_{diff}$=92.6%) and hip (P<.001, d=1.17, $\%_{diff}$=64.5%) joints.

Complex comparisons of the pause-bounce style differences revealed the hip difference to be significantly greater than the knee (P=011, d=.86) and ankle (P=.007, d=.89). The difference between the pause and bounce styles for the ankle and knee were statistically equal (P=.467, d=.23).

The average vGRF during this period of interest was significantly greater for the bounce style compared to the pause style (t_{19} =2.1, P=.049, d=.29, $\%_{diff}$=3.4%), whereas pause style vGRF impulse was significantly greater than the bounce condition (t_{19} =9.4, P<.001, d=2.6, $\%_{diff}$=138.3%). Explaining the greater impulse for the pause condition was a significantly longer time from lift off to when the barbell reached the same height as the peak of the bounce style (t_{19} =10.1, P<.001, d=3.0, $\%_{diff}$=93.4%).

The deadlift styles affected the angular joint positions at liftoff ($F_{2.7,51.9}$=8.6, P<.001, η^2_p=.312) and the instant of peak barbell bounce height ($F_{2.7,51.7}$=8.3, P<.001, η^2_p=.304) differently (Figure 2). At lift off, while the ankle (P=.001, d= 1.03, $\%_{diff}$=77.2%) and knee (P<.001, d= .89, $\%_{diff}$=16.2%) were significantly more flexed for the pause style, there were no differences in the trunk (P=.281, d= .13, $\%_{diff}$=1.7%) and hip (P=.469, d= .13, $\%_{diff}$=2.1%) angles. For the angles at the instant of peak barbell bounce height, whereas there was no statistical difference in trunk angle (P=.598, d=.08, $\%_{diff}$=1.3%), the ankle (P=.006, d= .62, $\%_{diff}$=155.8%), knee (P=001, d=.74, $\%_{diff}$=19.0%), and hip (P=.003, d=.64, $\%_{diff}$=8.7%) were significantly more flexed for the bounce style compared to the pause style.

(Figure 2 here)

Ascent Phase

For the entire ascent phase, the deadlift styles had different effects on ankle, knee and hip joint NJMI ($F_{1.4,22.6}$=23.5, P<.001, η^2_p=.610). Post hoc comparisons yielded significantly greater NJMI impulse for the pause style compared to the bounce style for the ankle (P=.010, d=.94, $\%_{diff}$=57.2%), knee (P=.002, d=.40, $\%_{diff}$=53.1%) and hip (P<.001, d=1.40, $\%_{diff}$=41.8%) joints. Complex comparisons of the pause-bounce style differences revealed the hip difference to be significantly greater than the knee (P<.001, d=2.1) and ankle (P<.001, d=.91). The difference between the pause and bounce styles revealed the ankle to be significantly greater than the knee (P=.037, d=.86).

The differences in ankle, knee and hip joint work were statistically equal between the two deadlift styles ($F_{1.2,22.1}$=3.1, P=.068, η^2_p=.157). Overall, significantly greater work was done during the pause style compared to the bounce style ($F_{1,19}$=12.6, P=.002, d=.27, $\%_{diff}$=18.8%).

During the ascent phase, the average vGRF (t_{19} =2.7, P=.014, d=.61, $\%_{diff}$=1.2%) and vGRF impulse (t_{19} =8.4, P<.001, d=1.87, $\%_{diff}$=27.6%) were significantly greater for the pause compared to the bounce style. The time to complete the ascent phase of the lift was significantly longer for the pause style compared to the bounce style (t_{19} =9.6, P=.001, d=2.13, $\%_{diff}$=25.8%).

Qualitative

Based on the RPE, participants perceived the pause strategy to require significantly greater exertion than the bounce strategy (t_{19} = 3.4, P=.003, 95% CI_{Diff}: 0.5 to 2.0, d=.90).

DISCUSSION

The results of the current investigation demonstrate that less mechanical training stimulus, as evidenced by the NJMI, work and vGRF impulse results, is experienced during the very early (lift off to peak barbell bounce height) phase of the bounce style compared to the pause style. The most remarkable result was that a reduction in NJMI, work, average vGRF and vGRF impulse persisted when the entire ascent phase of the styles was compared. The quantification of these differences provides the strength and conditioning professional with objective information concerning the biomechanical differences between the bounce and pause deadlift styles, which in turn will assist with training programing.

Interestingly, higher average vGRF were revealed during the lift off to peak barbell bounce height phase for the bounce style. Likely higher peak moments were experienced during this phase of the lift during the bounce style due to “catching” the barbell after the bounce. In depth analysis of coefficient of restitution and actual forces acting on the barbell from the collision were not considered in this work because of the differences various platforms and plates would exert on these characteristics.

But adhering to Newton's third law, once the barbell collides with the platform an immediate equal and opposite force will be applied to the barbell in the vertical direction aiding in the upward vertical displacement. Because some force is applied to the barbell is from an external source (ie not the lifter) the lifter's sustained force production requirements are not as great during this early phase. However, being an inelastic system, the barbell will lose upward velocity quickly and the lifter will have to suddenly reapply a large magnitude force to continue vertical barbell displacement, especially if heavily reliant on the collision force. The significantly more flexed angles of the ankle, knee and hip observed at the instance of peak bounce height during the bounce style support this theory as the muscle tension is not fully engaged.

Therefore, it seems reasonable that the muscles of the posterior chain, including the erector spinae, may be at greater risk of injury when the barbell suddenly loses velocity from the bounce and joint angles are more flexed. That is, within several centimeters of liftoff, when the hip is more flexed, the muscles of the posterior chain engage an increased load quickly. Further research should investigate the magnitude of the increased load and provide relative load data to strength and conditioning specialists.

It is possible however that the bounce could provide some potential benefit to the lifter. Peak barbell bounce height was used in favor of percentage of total movement because it is believed that the height of the individual could largely influence this. The participants in this study were all relatively similar in height as supported by the small standard deviation (refer to table 1). However, it is possible that the bounce could be more beneficial to shorter lifters versus taller lifters.

Future research should investigate the interaction between lifter height and bounce deadlifts. Secondly, the bounce may give the barbell more momentum throughout the lift and allow the lifter to use greater load intensities. Interestingly, a study conducted by Bishop et. al. (2014)(1) demonstrated that an “eccentrically loaded” deadlift resulted in the same one repetition maximum as performing the movement from the floor. Although, this version was not considered a “bounce” deadlift, the lifters were instructed to begin the concentric portion as soon as the barbell made contact with the floor(1). No methods for control were stated in the study and given the maximal load intensity it is likely the lifters were slightly bouncing the bar off the platform(1). In terms of maximal load the bounce may not have any perceived benefits, but further investigation is needed into the benefits to power production.

Furthermore, the lift off to peak barbell bounce height phase experienced much larger differences between styles at the joint level for both NJMI and work than the entire ascent phase. These greater differences indicate a more substantial contribution of force from the collision during the bounce style at lift off. Beyond, peak bar bounce height, the lifter can no longer heavily rely on augmentation provided by the collision, thus reducing the margin of difference between styles during the entire ascent phase. However, differences between styles for the entire ascent phase were still significant and quite considerable. Significantly greater NJMI and work were performed by the ankle, knee and hip during the pause style supported by the significantly greater average vGRF, vGRF impulse and longer contraction time for the pause style.

The greatest statistical difference in NJMI was observed in the hip. However, the knee and ankle NJMI were significantly reduced during the bounce style as well during the liftoff phase. Reducing the NJMI of the ankle and knee indicates less reliance on the ankle and knee extensor muscles to complete the lift. Typically, the knee extensors contribute the most to vertical bar displacement during the lift off phase of the conventional deadlift(2, 6, 10). When utilizing a bounce style, the knee extensors role in the lift is diminished, shifting reliance more heavily on the hip extensors and presumably the lumbar extensors for the entire range of motion. Furthermore, this change in muscle contribution could possibly indicate a shift in the neuromuscular synchronization pattern away from a desired triple extension pattern typically seen in many athletic movements. Future research should more thoroughly investigate the movement pattern changes due to the bounce, especially at the three traditional deadlift phase points (liftoff, knee pass and lock out).

Lastly, significantly lower RPE scores for the bounce style qualitatively support the lower NJMI and joint work magnitudes experienced during this particular style.

PRACTICAL APPLICATION

It is recommended to not use a bouncing style when performing the conventional deadlift for a multitude of reasons. Bouncing of the barbell allows lifters to move heavier loads without producing a proportionate amount of force and is reflected in the significantly lower NJMI and joint work magnitudes. In turn, that reduces the force production requirements necessary to complete the repetition with that particular load. Maximizing training stimulus must be considered and smaller mechanical stimuli in terms of force production requirements of muscle yield lesser physiological adaptations. Lower NJMI and joint work performed by the involved joints in conjunction with a substantial reliance on external collision forces dampens the mechanical stimulus on the posterior and knee extensor musculature.

Significant differences between conditions in RPE suggest that performing conventional deadlifts with a bouncing style is easier metabolically than utilizing a pause style as well. There are several theories that potentially explain this idea; the ability to utilize strain energy and greater barbell inertia as a result of the bounce. Due to the limitations of this study, the stretch shortening cycle cannot be quantified to provide evidence of how much strain energy is contributed. Significantly lower NJMI and joint work magnitudes support a lower metabolic cost for performing the conventional deadlift with a bounce style and implies less force is actually produced by the muscles involved. Less force required to move an object through the same range of motion yields less energy substrate required to perform the movement. Ultimately, the lessened metabolic cost can obstruct maximizing physiological stimulus placed on the lifter and thus further reduce adaptation.

In addition, the bounce style changes the movement pattern of the conventional deadlift with more similarities to stiff legged dead lifts. This then adjusts the synchronization pattern of certain muscles as well as their contributions to successful completion of the lift(4, 10). This is not only supported by the significant differences in kinematics at peak barbell bounce height, but by lower NJMI and joint work magnitudes at the ankle and knee during the lift off phase as well. Joint work is a product of torque multiplied by angular displacement, considering the load is the same; angular displacement may be slightly less. Resulting in a movement where the hips remain higher throughout the entire range of motion and supported by greater hip dominance throughout the entire movement. Altered kinematics will interfere with proper triple extension force and power development, which is necessary for many sport tasks(29). Utilizing the bounce style deadlift converts the conventional deadlift from a triple extension developer to a hybrid hip/lumbar extension isolation movement.

Not investigated in this study were the effects on intra-abdominal pressure, which plays an important role in anterior spinal stability and reduction of shear force experienced at the intervertebral disc(22). The bouncing of the barbell against the platform can affect the lifters ability to maintain optimal intra-abdominal pressure, optimized by the valsalva maneuver(22). Decrements to anterior spinal stability may result in altered spine kinematics that could portend increased injury risk.

The conventional deadlift provides many important benefits to athletic performance(16, 24, 29), injury prevention/rehabilitation(17, 25) and synthesis of soft tissue(26, 28). To maximize the benefits of deadlifting emphasis should be placed on proper technique and appropriate load intensity. Employing a pause style when performing the conventional deadlift will optimize training stimulus and the ability to use proper technique.

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FIGURE LEGEND

Figure 1. Typical barbell vertical position (black line) and velocity (gray line) curves from lift off to the end of the ascent phase during a bounce (top) and pause (bottom) repetition for the same subject. The local minima in the velocity curve defined the location of the peak height the barbell achieved after the bounce.

Figure 2. Joint angles at liftoff and peak barbell bounce height. Left graph is angles at liftoff, the right graph is angles at peak barbell bounce height (in degrees).

Table 1. Descriptive statistics for participant characteristics

Characteristic	Mean±SD
Age	22.9±2.7
Mass (kg)	82.7±10.9
Height (cm)	177.0±4.9
1RM (kg)	165.8±35.9
1RM to body mass ratio	2.01±0.4
Deadlifting experience (yrs)	3.4±3.3

SD: standard deviation; 1RM: one repetition maximum

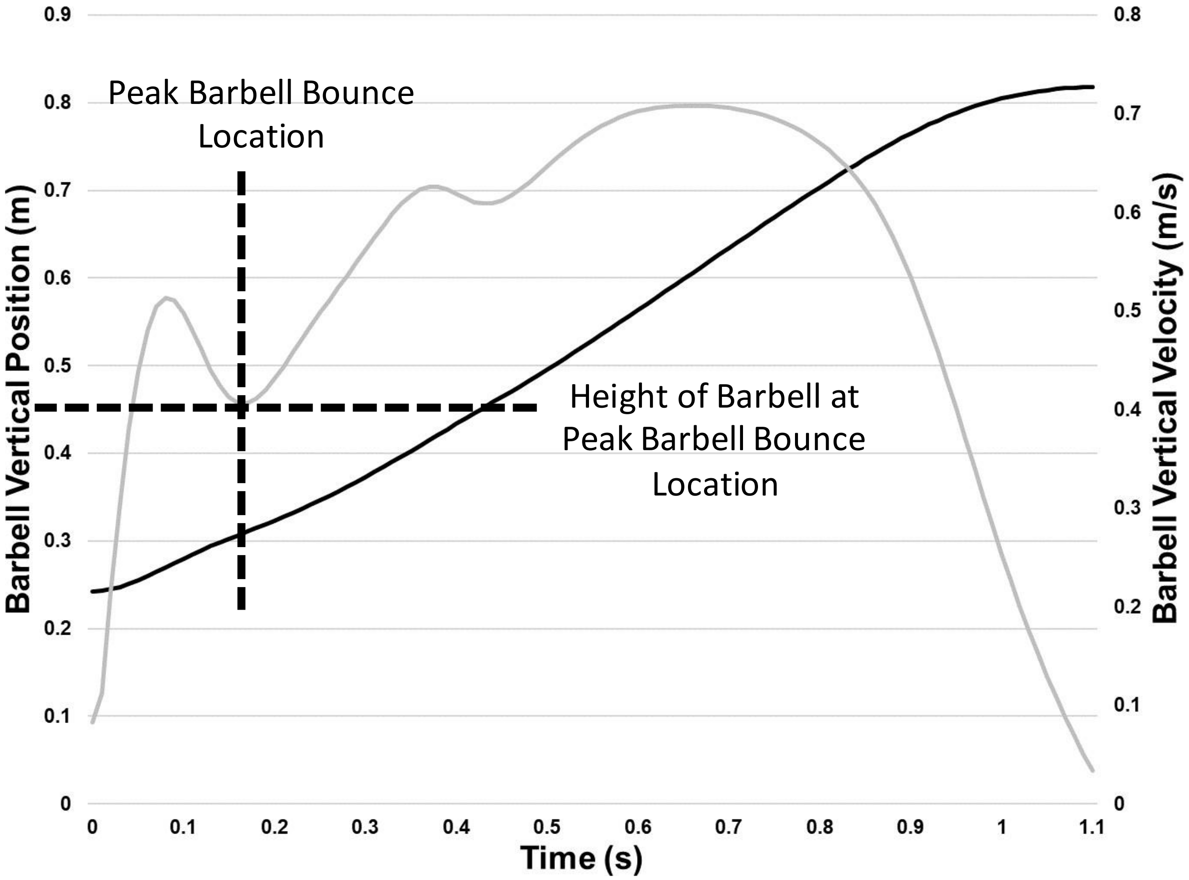
Table 2. Outcome measures (mean±standard deviation) for the Lift Off to Peak Barbell Bounce Height and Ascent phases.

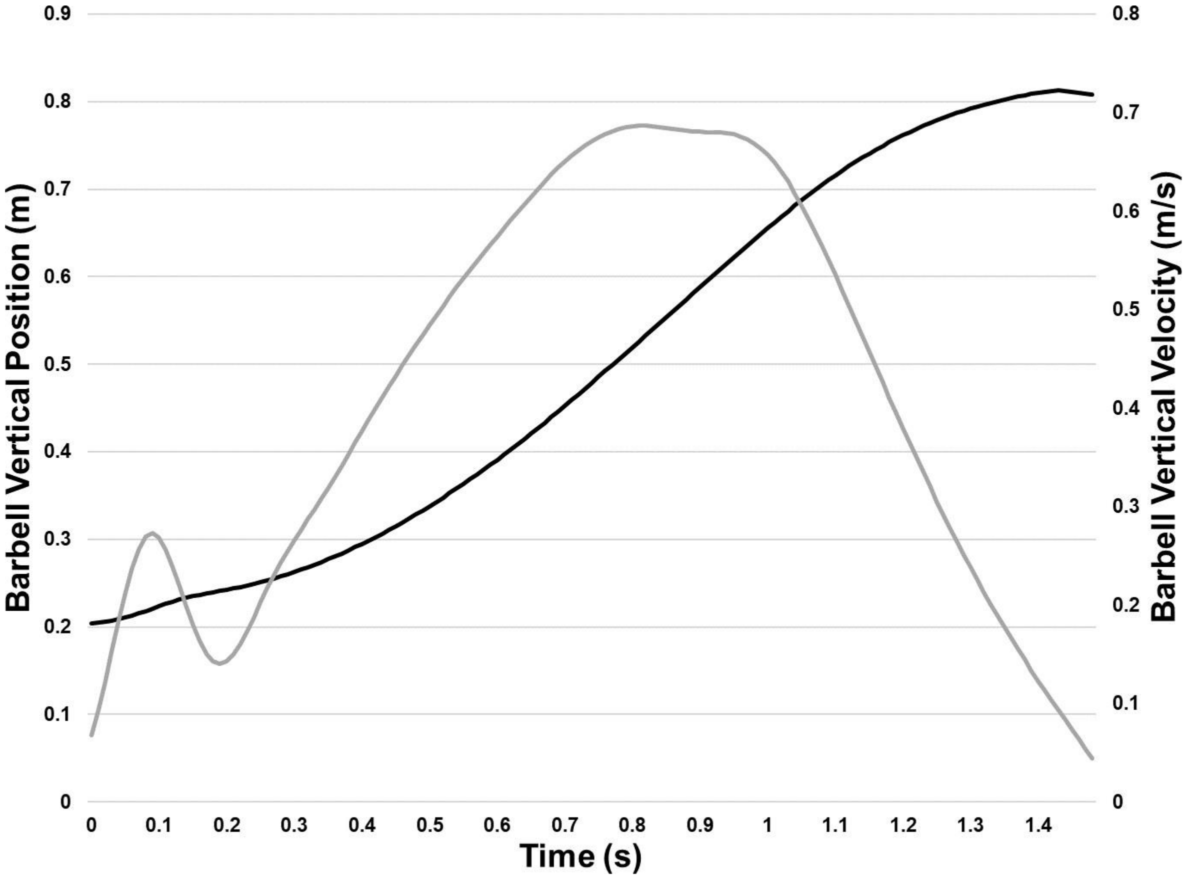
	Lift off to Peak Barbell Height Phase		Ascent Phase	
	Bounce	Pause	Bounce	Pause
NJMI (Nm•s/kg)				
Ankle	.22 ± .10	.45 ± .18*	.68 ± .42	1.22 ± .70*
Knee	.09 ± .10	.19 ± .16*	.13 ± .20	.22 ± .25*
Hip	.68 ± .36	1.66 ±.51*	2.47 ± .63	3.78 ± 1.15*
Work (J/kg)				
Ankle	.05 ± .04	.12 ± .07*	.09 ± .06	.18 ± .11
Knee	.06 ± .08	.16 ± .19*	.13 ± .23	.19 ± .27
Hip	.26 ± .19	.50 ± .23*	1.96 ± .50	2.27 ± .58
vGRF Average (N/kg)	2.70 ± .32†	2.61 ± .29	2.44 ± .26	2.47 ± .27*
vGRF Impulse (N•s/kg)	.48 ± .21	1.26 ± .37*	2.45 ± .43	3.23 ± 70*
Phase time (s)	.17 ± .08	.48 ± .12*	1.00 ± .15	1.30 ± .20*

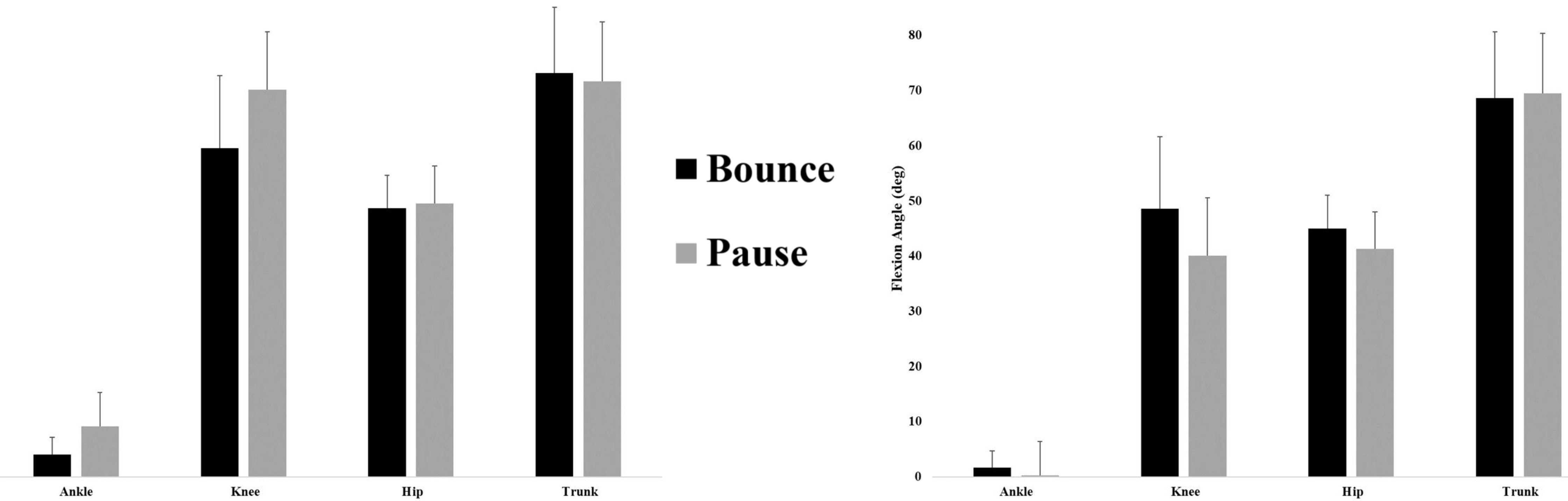
NJMI:net joint moment impulse, vGRF: vertical ground reaction force

*Pause significantly greater than Bounce (P<.05)

†Bounce significantly greater than Pause (P<.05)


Peak Barbell Bounce Location
Height of Barbell at Peak Barbell Bounce Location
Barbell Vertical Position (m)
Barbell Vertical Velocity (m/s)
Time (s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1


Barbell Vertical Position (m)
Barbell Vertical Velocity (m/s)
Time (s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4


Bounce
Pause
Ankle
Knee
Hip
Trunk
Flexion Angle (deg)
90
80
70
60
50
40
30
20
10
0
Ankle
Knee
Hip
Trunk