THE EFFECT OF DIFFERENT WEIGHT PLATES
ON THE BIOMECHANICS OF THE BENCH PRESS

A Thesis
by
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Abstract

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ON THE BIOMECHANICS OF THE BENCH PRESS

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Anecdotal evidence suggests that bumper plates impact lifts in powerlifting and weightlifting different than standard cast iron plates, but very few studies have investigated how bumper plates affect the biomechanics of any lift. The aim of this study was to examine if there were any differences in bench press biomechanics when comparing lifts with bumper versus standard plates. Eleven resistance-trained participants performed the bench press using both bumper and standard plates at 70%, 80%, and 90% 1RM. The participants were blinded to whether they were lifting bumper or standard plates by boxes covering the plates on the barbell. The participants had a 1RM of 99.51 ± 32.90 kg, and lifted 71.68 ± 23.28 kg at 70% 1RM, 81.29 ± 26.23 kg at 80% 1RM, and 91.61 ± 30.10 kg at 90% 1RM. Motion data was captured by an eight-camera motion capture system and EMG data was recorded for the anterior deltoid, pectoralis major, and triceps brachii. Repeated measures ANOVAs showed a significant main Weight effect for Time-Under-Tension (TUT) ($p < 0.001$), Total Work (TW) ($p < 0.001$), and EMG ($p < 0.001$), and a significant Weight x Joint interaction effect for average joint moment ($p < 0.001$), impulse ($p < 0.001$), and peak joint moment ($p < 0.001$). However, there were no significant differences observed between the different weight plates for any of the measures. The main findings of the study suggest that there are no biomechanical differences between using bumper plates or standard plates during the bench press lift.

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Dedication

I would like to dedicate this thesis to my mom and family. Without their love and support, I would have never made to the place where I am today.

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Introduction

The flat barbell bench press is one of the most popular forms of free weight resistance exercise because the movement is easily learned and can be done with limited equipment. Only a bench, a rack, a barbell, and weight plates are needed to perform the movement. Bench press is regularly integrated into workout programs to improve strength, power, hypertrophy, muscle endurance, and injury prevention.[1] It is a multi-joint exercise which primarily trains the pectoralis major, triceps brachii, and anterior deltoid along with other stabilizing muscles. [1–7] Strength and conditioning coaches utilize the bench press as a primary method prior, during, and after a training program to evaluate an athlete's upper body strength through a one repetition maximum (1RM) protocol. [1]

Previous studies have investigated various aspects affecting the bench press. Studies have considered technique variations, such as changing grip width, [8,9] while other studies have compared the effectiveness of training with specialty barbells versus a standard barbell in improving bench press performance. [2,5,10,11] Many investigators have also examined the effect of fatigue on bench press performance, [4,12–16] showing for example, that the elbow of the non-dominant limb fatigues faster than the dominant limb which could cause barbell instability, [4] or that there is more bar movement variability in the horizontal and vertical plane during the bench press as fatigue increases for the lifter. [16]

Very few studies have considered the effects of varying mechanical and/or inertial properties of the barbell and weights on bench press performance. One such study looked at a lifter's ability to detect balance differences caused by alterations in weight or centers of mass, and the authors found lifters are more perceptive to a change in the center of mass than a change in weight. [7] The mechanical properties of the barbell itself differ from manufacturer to manufacturer and are affected by the steel alloy used, distance between sleeves, diameter of the barbell, and length of the sleeves. [17,18] Further, a lifter could also use different types of weight plates during their lift. The two most common varieties of weight plates are standard plates and bumper plates. Standard plates are traditionally made of cast iron and are best suited for powerlifting tasks such as bench press and squat, [19] whereas bumper plates are commonly made of rubber and are designed for Olympic lifts such as cleans and snatches. [20,21] Although the mass of these plates are clearly defined and should be identical for the same weighted plate, bumper plates can be up to three times wider than standard plates. [19–21] These differences in mechanical properties of the barbell or type of plates might affect the biomechanics of the lift by affecting the center of mass of the load, amount of bar deformation, and/or moment of inertia of the bar. [17,18,22–25] Because different plates are generally used for different lifting activities, it is important to consider these mechanical differences. With financial constraints, small Division III schools, home gyms, and/or fitness centers may decide to purchase one type of weight plate, for example bumper plates only, to reduce costs. [26–28] Therefore, it is imperative to know how potential differences when using different weight plates affect the biomechanics of a lift such as the bench press in order to reach desired training program outcomes and prevent injuries.

There are two factors that should be considered when comparing the use of standard cast iron plates versus bumper plates. First, the thicker width of the bumper plates increases the distance of the center of mass of the load from the supports when compared to standard plates. This increased center of mass can enlarge the amount of deformation of the barbell. Anecdotal evidence states the increased bar deformation could alter an athlete's performance during the lift. [24,25] For an example, using bumper plates instead of standard plates could augment a lifter's deadlift by 27.3 kg. [25] However, there have been no peer-reviewed studies to date examining the effects of bar deformation on powerlifting activities, and only a handful of studies have examined bar deformation and its effects on Olympic lifts. [17,29] A second factor to consider is the effect of wider bumper plates on the moment of inertia of the barbell. [22,23] A mass further distributed from the center point, or axis of rotation, increases the object's moment of inertia. Therefore, a bar loaded with bumper plates would have an increase in moment of inertia over a standard plate-loaded bar. Since the moment of inertia is directly proportional to the resistance to angular rotation, the greater the moment of inertia, the harder it is to move a weight around a rotation point. [23] It is not clear what effect this would have on the ability of a lifter to control the trajectory of the bar during heavy lifts. The moment of inertia can also affect the sensation of object feels in a person's hands. Studies have shown that for certain activities people are ten times more sensitive to a change in a moment of inertia than a change in mass. [22,30]

The purpose of this study was to examine the biomechanical differences, specifically kinetics and muscle activation, during the bench press when using either bumper plates or standard plates. Since previous research and anecdotal evidence suggests that bar deformation affects total work, we hypothesized bumper plates will show increases in total work which will also cause an increase in time under load. We further hypothesized the increased moment of inertia of the bumper could reduce the lifter's ability to make small adjustments to force production during the lift, and therefore it would cause an increase in muscle activation as well as an increase in the joint moments at the shoulder and elbow.

Literature Review

The flat barbell bench press is one of the most widely used resistance training exercises to both measure and increase upper body strength.[1] This review will focus specifically on the equipment used for the bench press, with special interest on the bar and types of weight plates. Furthermore, the review will cover the general bench press technique and the effects of technique variations and barbell types on the biomechanics and performance of the bench press.

Equipment

General Equipment

The equipment needed for a standard bench press is a standard barbell, a flat bench, a racking mechanism, and weight plates. A power rack is a versatile solution for a weight room with minimal space and tight budget. A power rack allows for multiple lifts to be performed on the same piece of equipment instead of buying specialized equipment such as squat and bench press racks. An adjustable bench instead of a flat bench can be utilized to give more flexibility to a weight room without much difference in cost. With an adjustable bench, the angle of the back rest can be adjusted to accommodate different lifts. A typical barbell has a thin cylindrical shaft made of steel where the bar is gripped, and two wider sections called sleeves on each end where the weights are loaded. [17] The sleeve length, distance between sleeves, and barbell diameter can differ between manufacturers, but the lengths are standardized depending of the governing body of the sport such as the International Weightlifting Federation. [17] The final piece of equipment needed for the bench press is the weight plates. Standard weight plates have traditionally been made out of cast iron but recently rubber bumper plates have become popular alternatives in college and home gyms. Standard cast iron plates are thinner than bumper plates, so a larger number of standard plates can fit on the barbell allowing for a larger mass to be lifted which makes them ideal for powerlifting exercises. On the other hand, bumper plates are made of an iron core within a thick protective rubber housing. This design is recommended for Olympic lifts because it allows bumper plates to be dropped repeatedly without causing damage to the floor, the barbell, or the plates themselves.

Financial Considerations

A small Division III college or a person building a home garage gym might struggle with the costs of all the necessary equipment to build an effective gym. As the competition to recruit top athletes has increased, schools have started to market their facilities as a way to differentiate themselves from their competition. [26] Conversely, recruiting student athletes can be critical for a Division III school to fill its student body. Student athletes can account for an average of 25% of the student population at that institution, but that percentage can double if the school has a football team. [28] However, most Division III schools only allocate around 5% of their budgets to athletics. [28] Even though the cost of barbells can vary widely depending on the type of steel alloy, bearings in the sleeves, and the manufacturer, only one barbell is needed per lift and the school or individual could use the barbell for several different lifts throughout the weight room. [31] When considering the weight plates, multiple plates are required to tailor the load needed for a desired adaption for each individual. For example, if an athlete wanted to do bench press at 127.5 kg (255.0 lb), the smallest number of plates required would be four 22.5 kg (45 lb), two 4.5 kg (10 lb) plates, and two 2.3 kg (5 lb) plates for a total of eight different plates for one lift. Consequently, costs for weight plates could escalate very quickly depending on the size of the weight room, especially if the school or individual was buying bumper plates for Olympic lifts and the standard pates for powerlifting exercises. But as budgets start to get reduced and athletic departments are forced to make hard decisions, small Division III institutions could decide to choose one style of weight plates, e.g. only bumper plates, over the other as a cost saving measure. [27]

Mechanical Properties of the Barbell

When designing a barbell, a manufacturer can influence the strength of the barbell and the amount of deformation the barbell undergoes by altering the mechanical properties of the barbell, such as steel alloy used, distance between sleeves, diameter of the barbell, and length of the sleeves. [17,18] A standard barbell undergoes stress during resistance training causing the bar to deform. [17] Deformation is any change in shape due to an application of a force. [23] According to Hooke's Law, the size of the deformation is directly proportional to the size of the force. [23] In other words, large forces cause large deformations while small forces cause small deformations.

To calculate the amount of barbell deformation, the following equations for a beam with ends overhanging supports with two equal loads applied at symmetrical locations can be used (Figure 1). [18]

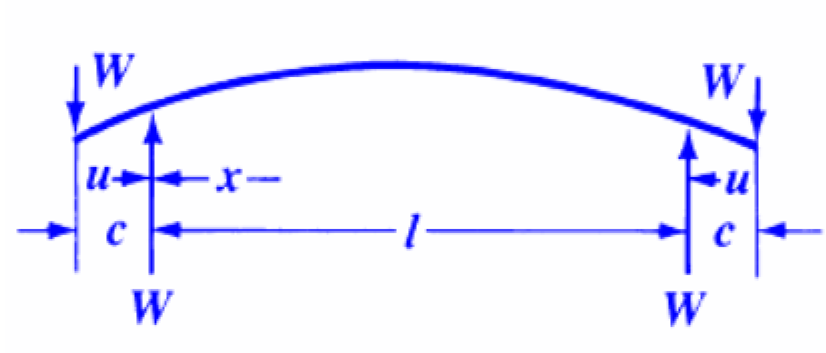

Figure 1: Drawing of a beam with ends overhanging supports with two equal loads applied at symmetrical locations. **Machinery's handbook** 18th ed.; 2008; 2012 p. 260

All units are considered to be in Imperial Units. [18]
W= load on the beam
I= moment of inertia for the cross section of the beam
c= distance between the center of mass of the load (W) and the support
E= elastic modulus (Young's Modulus). Relationship between material stress and strain
l= distance between supports

The equation for finding deflection at the ends of the bar is [18]:

$$\frac{Wc^2}{6EI}(2c+3l)$$

The equation for finding defection at the center of the bar is [18]:

$$-\frac{Wcl^2}{8EI}$$

In this equation: W is the amount of weight on the bar. The variable "c" is the distance of the center of mass of the weights to the nearest hand, l is the distance between hands, E is the elastic modulus of steel, and I is the moment of inertia of the cross section of the bar. [18] Using the same barbell and load, the only difference in the equations between standard and bumper plates would be "c", which is the difference in center of gravity from the load to the supports.

A bumper plate can be around three times as wide as a standard plate. [19–21] This increased width would increase the amount of bar deformation. [18,24,25] Using the same barbell, a barbell loaded with 184.1 kg (405.0 lb) using four *Sorinex* bumper plates with each plate having a width thickness of 9.53 cm (3.75 in) on each side would have a center of mass distance increase of 13.97 cm (5.50 in) compared to using four York standard plates with a width thickness of 2.54 cm (1.00 in). [18,21,24,25] This increased center of mass would lead to increase in bar deformation of up to 68%. [18,24,25]

Chiu et al. studied the mechanical properties of different barbells to determine their stiffness. The authors believed the amount of stiffness could help determine whether a bar was appropriate for weightlifting or powerlifting exercises in the weight room. [17] The authors took the bars through a four-point bending test using squat stands as supports. The squat stands were distanced at grip distance between the two hands for the clean pull. The barbells were then loaded in 50 kg increments and the amount of deformation was calculated and compared to the bending moment to find the apparent stiffness of each bar. [17] The barbells with the largest deformation were considered the least stiff bars while the bars with the least amount of deformation were considered the more stiff bars. The authors recommended the least stiff bars for weightlifting since more deformation is desired for weightlifting competitions. The stiffest bars were recommended for the activities which deformation would not be desired under a heavy load such as a squat. [17]

Since bumper plates are up to three times as wide as a standard plate, the moment of inertia would also be different between the different types of plates. The moment of inertia of an object is the measurement of rotational inertia. [23] The further the center of mass is located from the point of axis the greater the value for the moment of inertia which would be increased by the wider width of the bumper plates. The greater the value for rotational inertia for an object, the greater its resistance to change in angular velocity around a fixed axis point. [23] The equation for find the moment of inertia (I) for a center of the barbell would have two masses (m) with distance (R) from the center [23]:

$$I=2mR^2$$

The moment of inertia along with mass and center of gravity are critical properties in helping a person describe the feel of a handheld object. [22,30] The differences of mass and center of gravity between different objects can be easily expressed by an individual. On the other hand, people have a hard time describing the differences between moment of inertia of different objects and often use descriptions of mass and center of gravity in response to describing the differences in the way the objects feels. [22,30] The point at which a person can detect a small change in intensity, such as mass or moment of inertia, is termed the Just Noticeable Difference (JND). By finding the JND, the differences in sensation of intensity can be expressed using the Weber ratio. The Weber ratio is found by taking the JND divided by the intensity. For example, a person is told to lift several objects at small increasing weight increments starting at 5 kg intensity till they notice a difference in weight. The person first notices the difference in weights at 5.5 kg. The JND for that person would be 0.5 kg when starting with 5 kg intensity. The Weber ratio would therefore be 0.5 kg (JND) divided by the intensity (5 kg) which would equal 0.10 or a 10% difference. This ratio is fairly constant among all intensities. It has been shown that a subject will notice a Weber ratio of 20% for the moment of inertia. [22] Another study reported a Weber ratio of 28% for difference in the moment of inertia to be detected. [30] In other words, both studies showed the Weber ratio of inertia is ten times more perceivable than the 2-3% Weber ratio of noticing the difference between weights. The authors also noted men were more sensitive to the differences of inertia than women. [22,30] Piper et al. noticed subjects are more sensitive to a difference in the location of the center of mass of the load than differences in mass of load on the barbell. [7]

Types of Barbells

Different types of specialized barbells have been designed in order to create potentially varying adaptations during training. [2,5,10,11] The Tsunami barbell was created to increase power during the bench press and is made of special composite material that allows for much more flexibility than a standard barbell (Figure 2). [2] A Freak bar is a barbell designed to improve lateral force ability during the bench press by utilizing specialized grips allowing for pushing and pulling action on the barbell (Figure 2). [11] A third type of barbell variation for use during a bench press is the Cambered bar (CB). [5,10] The full range of motion of the primary movers in a bench press is limited by a standard barbell because it is a straight line that touches the chest. [5,10] The CB is a specialty barbell developed to help increase the range of motion of the primary movers during a bench press repetition. [5,10] The CB has a U-shape in the middle of the bar with a depth of about 10 cm to allow room for the torso when the barbell is lowered to the chest (Figure 2). [10] The effects of the specialty barbells versus standard barbells on muscle activity during the bench press are summarized in the subsection of *Barbell Type* under the *Bench Press Technique Variations*.

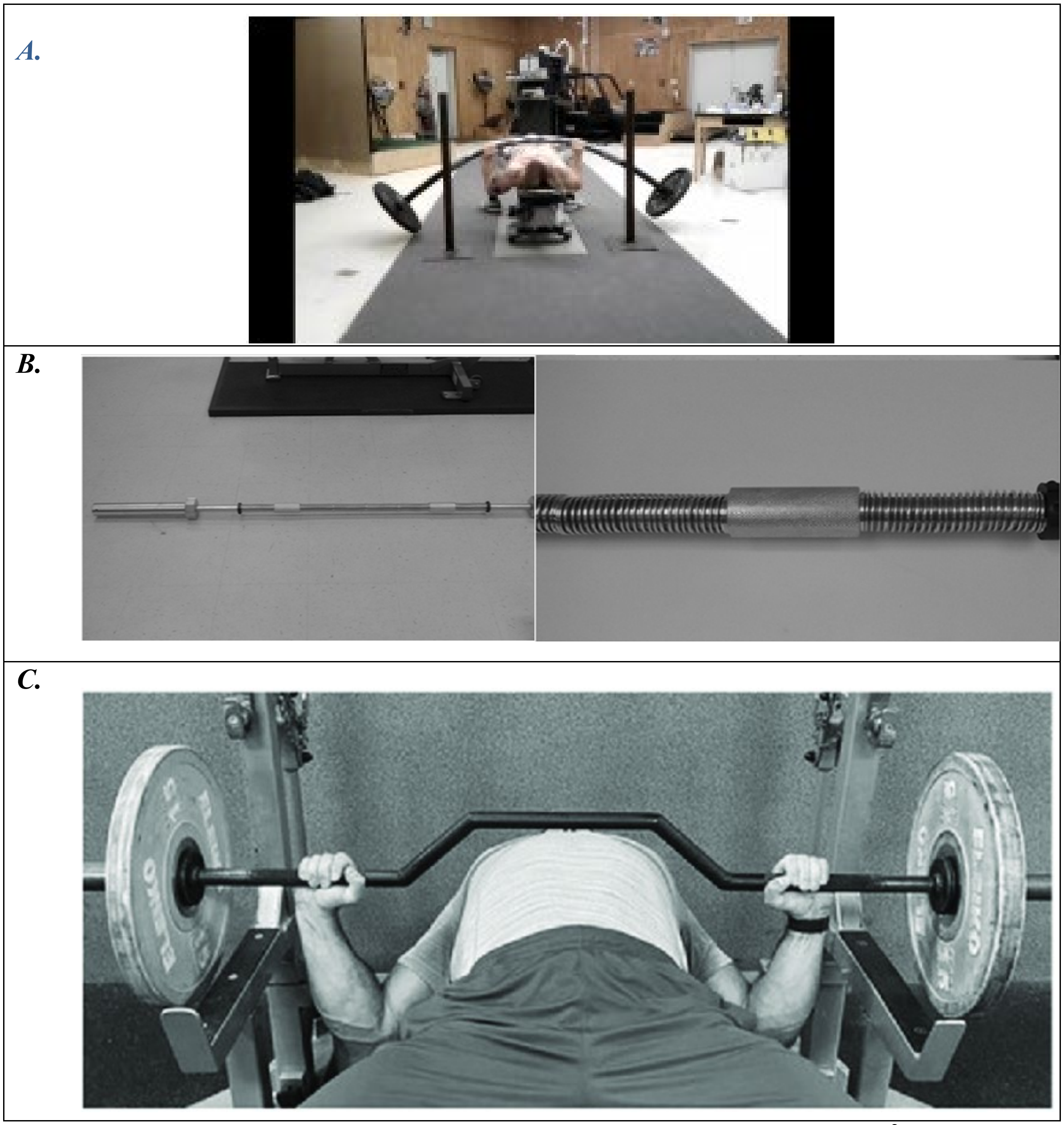

Figure 2: Different Barbell Variations: **A.** Tsunami Barbell from Jakayla et al.[2] **B**. Freak Bar from Ghigiarelli et al.[11] **C.** Cambered Bar from Krzysztof et al.[5]

Bench Press Biomechanics

Technique

The traditional flat barbell bench press begins with the lifter positioning themselves on a bench by laying supine with their eyes positioned underneath the racked barbell and gripping the barbell slightly wider than shoulder width with a closed pronated grip. The head, shoulders, and buttocks rest flat against the bench and the feet are flat against the floor in a five-point contact position which is maintained throughout the press. The bar is lowered to the chest (descent phase), and then pressed upwards until the elbows reach full extension (ascent phase). [1] The descent phase is the eccentric portion and the ascent phase is the concentric portion of the bench press. During the descent phase, the bar is lowered slowly to touch the chest at the nipple level while keeping the wrists stiff and the forearms parallel to each other and perpendicular to the ground. After the barbell touches the chest, the ascent phase begins with the bar being pushed upward with a slight backward movement while keeping the wrists stiff and the forearms parallel to each other and perpendicular to the ground. [1] The bench press occurs in the transverse plane of motion with the wrists in neutral, elbows in flexion, and shoulders in horizontal shoulder abduction during the descent phase and the wrists in neutral, elbows in extension, and shoulders in horizontal shoulder adduction during the ascent phase.

When the load is increased, variations in the general technique have been observed. The horizontal displacement of the barbell shifts from the nipple line towards the shoulder as the load is increased from 70% to 100% of 1RM. [32,33] This shift towards to the shoulder helps decrease the moment arm in order to decrease the torque exerted by the shoulder joint. [33] Fatigue also shifts the barbell path towards the shoulder and increases the time to complete the repetition, [12] making the final repetition of a set to fatigue resemble the successful 1RM attempt. [12] Besides a shift in horizontal displacement as the load increases, the vertical velocity during the ascent phase decreases and the vertical velocity of the descent phase decreases. [32]

The force generated by primary movers during the bench press is historically believed to a vertical force pushing against the gravitational force of the weights. [34] However, studies have shown forces are simultaneously created vertically and laterally outward against the length of the bar by the lifter. [3,34] Duffy et al. tested subjects at 80% and 100% IRM with a barbell specially designed to measure vertical and horizontal forces. The authors found the amount of lateral force was 25% of vertical force, and the amount of lateral force needed remained the same for both the 80% and 100% 1RM efforts. [34] Another study demonstrated as the grip width increased, the amount of lateral force also increased. [3]

The one repetition maximum (1RM) is the maximum weight that can be lifted for a single repetition and the method for measuring strength. The National Strength and Conditioning Association has published the following protocol for flat barbell bench press 1RM testing [1]:

1. Allow the athlete to warm up with a load that easily allows for 5-10 repetitions.
2. Provide 1 minute rest period.
3. Estimate a warm-up load that allows for 3-5 repetitions by increasing the load 10-20 pounds.
4. Provide a two-minute rest period.
5. Estimate a near maximal load that will allow the competition of 1-3 repetitions by adding either 10 to 20 pounds or 5 to 10% of the previous load.
6. Provide a 2–4-minute rest.
7. Make a load increase of either 10-20 pounds or 5 to 10% of the previous load.
8. Have the Athlete attempt a 1RM.
9. If successful provide a 2-4 rest and repeat steps 7-8. If not successful decrease the load by 5 to 10 pound or 2.5 to 5% of the previous load and attempt step 8.

Prime movers

The prime movers of the bench press are the pectoralis major, anterior deltoids, and triceps brachii. [1,2,4–6,8,32] During the descent phase, all the primary movers show a similar EMG activity, while during the ascent phase at 70%, 80%, and 90% of 1RM, the EMG activity for all of the prime movers increase as the load increases (Figure 3). [32] However, at 100% of 1RM, the muscle activity of the pectoralis major decreases and the EMG activity of the anterior deltoid and triceps brachii both increase. [32] Because of this shift in activity, the role of the pectoralis major changes to a supportive prime mover, while the triceps brachii and anterior deltoid take over the role of the primary prime movers. [32]

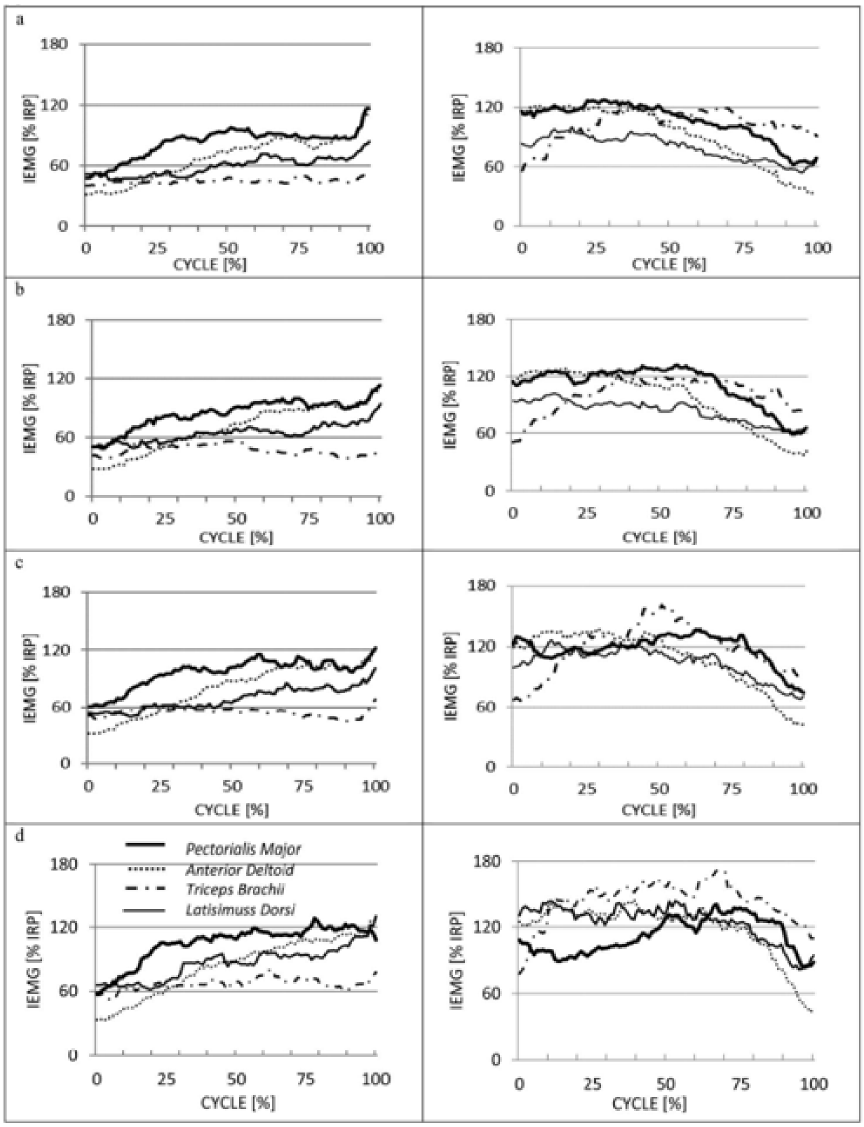

Figure 3: EMG Activity of the Pectoralis Major, Anterior Deltoid, Triceps Brachii, and Latissimus Dorsi during the Bench Press: descent phase (Left Side) and ascent phase (Right Side) at a) 70%, b) 80%, c) 90%, d) 100% of 1RM. Taken from Krol and Golas 2017 Figure 1[32]

Fatigue

The goal of any training program is to provide the body with an overload to force adaptions to improve performance. In order to reach the desired adaption outcomes for a strength training program, a strength and conditioning coach needs to balance needs of the sport, order of exercises, load, training volume, and recovery periods. [1] Failure to balance to load, training volume, and recovery can lead to overtraining. Overtraining is the accumulation of training stress that can lead to decrease in performance that can last from days to several months. [1] Traditionally training volume has been calculated by multiplying the number of sets by the number of repetitions. [1,14] But this calculation does not factor in the total work performed by the athlete during the concentric and eccentric phase of the repetition. [14] McBride et al. compared volume load (VL), maximum dynamic strength volume load (MDSVL), time under tension (TUT), and total work (TW) as methods to calculate volume during resistance exercise. [14] TW (work performed during the concentric and eccentric phases) was determined to be the most accurate method to determine work volume. [14] Therefore, it is important factor not only the volume load but also the amount of work an athlete is accumulating a lifting program in order to help deter overtraining.

If not monitored correctly, fatigue could cause injury, change barbell kinematics, and result in undesired adaptions. [4,13,15,16] Fatigue increases the total distance traveled by the bar as well as the time to complete a repetition, [12] further increasing the time under load of the lift. Because fatigue reduces the body's ability to control the trajectories of the upper limbs, the lifter may lose bar stability during the bench press. [16] Hang et al. found the force acting on the elbow increased with fatigue, and elbow strength decreased with the onset of fatigue.

This increase in force and decreased strength of the elbow could lead to injuries in both the elbow and upper extremity. [13] Williams et al. found the non-dominant side elbow flexors fatigue faster than the dominant side during exercise, but did not lead to different endurance time. [15] Several studies have found the dominant arm is more efficient in reaching tasks by using less muscle torque at the shoulders and elbow compared to the non-dominant arm. [35–38] During the bench press, the dominant side showed higher EMG activity compared to the non-dominant side. [4] During fatigue, the elbow joint angle can also be reduced causing upper body instability which could cause the lifter to lose control of the barbell. [16] As fatigue increases bar velocity decreases which can further increase the time under load for the athlete. [13]

The bilateral deficit (BLD) might also be a source of unwanted fatigue and adaptation. BLD is the difference between maximal bilateral contraction and maximal unilateral contraction of a single limb. [39] The bilateral index is calculated by the equation [39]:

$$\text{BLD\%} = 100 \cdot \left(\frac{Bilateral}{Right\ Unilateral + Left\ Unilateral}\right) - 100$$

A negative value of BLD% value shows a BLD. [35] Since the bench press is a bilateral movement, BLD could potentially affect the motor coordination during the activity. For example the average BLD between concentric and eccentric contractions is 10%. [35] BLD has been shown to be more prevalent in the upper limbs and increases with greater postural stability requirements. [35] One cause of BLD is inhibition of type II muscle fibers during a bilateral movement. [35] Type II muscle fibers, such as triceps brachii, are utilized for activities requiring a production of a large amount of force in a short amount of time. [35] Krysztofik et al. compared the peak EMG of the anterior deltoid, pectoralis major, and triceps brachii of the dominant and non-dominant side of the body during bench press to failure at 50% and

90% 1RM. The authors found the triceps brachii was the only muscle to increase EMG activity during the final repetitions before failure, while the EMG activity of the other muscles did not differ between the final repetitions before failure. [4] As the muscles fatigue, the body recruits more muscle fibers to maintain force production. During the final repetitions of the bench press, the dominant arm recruits the triceps brachii to help produce the additional force required by the system. This additional force production could further increase the BLD during the lift. Additionally, the dominant arm is less effective at novel load compensation then the non-dominant arm. This can cause the dominant arm to over compensate and overshoot the final desired position of the arm. [37] The unfamiliar feel of increased inertia, for example, when using different weight plates and increased BLD could cause to the dominant arm to overshoot the end of the repetition causing further bar instability. Increased fatigue could also cause more adaptation in the dominant arm as the triceps brachii becomes more active causing further BLD.

Bench Press Technique Variations

Grip Width Variations

One of the most common changes in bench press technique is a change in grip width. There have been previous studies which have compared altered grip widths as a variation to the standard bench press. [8,9] The standard bench grip is 150% of biacromial distance, a narrow grip is biacromial distance, and wide grip bench is 200% of the biacromial distance.[8] Biacromial distance is defined as the distance between the lateral edges of the two acromion processes. Research suggests no difference in muscle activation of the prime movers between the different grip widths performing the bench press. Saeterbakken et al. showed a lower activation of biceps brachii during the narrow grip compared to the wide and standard grip. [8] Additional studies observed no difference in prime movers between the narrow, standard and wide grips. [9] However, wide grip has been shown to increase bench performance because of a shorter bar path to the chest compared to the narrow and standard grip. [9]

Barbell Type

Besides looking at variations in grip width, researchers have also studied the effect of specialty bars on the muscle activity and performance of the flat bench press. Jakiela et al. found the Tsunami barbell increased the muscle activity of the pectoralis major, lateral deltoid, posterior deltoid, and triceps brachii compared to the standard barbell at 40% of the 1RM. [2] Another researcher compared the effects of a 6-week bench press program using the Freak bar or a standard barbell and found there was no significant difference in 1RM, peak force, or peak pulse between the Freak bar and the standard barbell after the six week training program. [11] Krzysztofik et al. tested the difference in EMG muscle activation of the triceps brachii long head, triceps brachii lateral head, pectoralis major, and anterior deltoid between standard bar and CB at 50%,70%, and 90% of 1RM. [5] Results indicated the CB resulted in a decrease of EMG activity in the triceps brachii long head, triceps brachii lateral head, and the pectoralis major, and an increase in the EMG activity of the anterior deltoid when compared to EMG activity for the standard barbell. [5] The authors surmised this decrease in muscle activity could be due to increased range of motion which would cause greater increase of storage and release of energy during the stretch shortening cycle during the eccentric cycle of the lift. [5] An alternative study tested the difference in power output between a standard barbell and CB by measuring the velocity of three repetitions at 50% of 1RM. [10] The authors found the CB bar was lifted with a greater velocity. Since power equals force times velocity and the force would be the same for both barbells, the velocity increase would show a higher power output. The authors also found the increased range of motion of CB also increased the time under load (TUL). The amount of TUL would compound after every repetition and may cause the athlete to fatigue faster than a standard barbell. [10] The increased range of motion of the Tsunami barbell and the CB would make them a good option in training overhead sports who want to increase upper body power emphasizing the anterior deltoid while also training the pectoralis major and triceps brachii. [2,5,10]

The Effect of Bar Deformation on Technique

The amount of deformation of the bar is often referred to as “whip” in power lifting and weightlifting. [17,24,25,29] There is anecdotal evidence stating the more whip a bar has the more weight can be lifted by an individual. [17,25,29] Weightlifters are often taught to help use the elastic energy stored in bar deformation to help them redirect the energy during the upward extension of the clean. [17,29] There is also anecdotal evidence that amount of weight a powerlifter can deadlift can be improved by 50 to 60 lb. by making use of the total deformation of the bar. [24,25] It has been suggested that this amount of whip can be further increased by using bumper plates instead of standard Olympic plates. [25] The amount of whip can be increased, shown in the beam equations, by increasing center of mass of the load from the supports. Manufactures have started to sell specialized deadlift bars that have a small diameter and longer length compared to a standard barbell. [40] The amount of whip for the bar is advertised as potential way for the lifter to increase their performance in the deadlift. [40]

Chiu et al. first looked in the effects of bar deformation on the clean pull. [29] The clean is an Olympic lift in which the lifter lifts a weight off the floor from a squatting position and accelerates the weight up the torso and catches the bar on the shoulders. The clean is a purely explosive weightlifting movement consisting of a first pull, which brings the bar to the knees, and the second pull, which brings the bar to the shoulders. [1] Chui et al. video-taped nine subjects performing the clean. Reflective markers were placed on each end of the barbell and reflective tape was wrapped around the center of the barbell. The subjects performed the clean at 85% of their self-reported 1RM. The ends of the barbell were lower in height than the center of the bar during the lift off phase, but the ends of the barbell and the center of the barbell were equal in height during the first and second pulls phases of the lift. However, even with the differences in height during the lift off phase, no differences in work between the center of the barbell and the ends of the barbell were found throughout the lift. [29]

Summary

The flat bench press is an effective resistance training exercise to both build and access upper body strength. The equipment needed to perform the bench press is minimal but choosing the right equipment due to budget constraints might cause issues for desired outcomes of the exercise. The barbell is made of steel which is an elastic material and will deform while under load. [18] Previous studies have looked in muscle activation during the standard bench press as well as bench variations such as grip width and barbell variation. [2,8–11] There is anecdotal evidence that barbell deformation can aid in both weightlifting and powerlifting activities. [24,25,29] Only one previous study has looked in the mechanical properties of the barbell, [17] and one study has researched how the mechanical properties of the barbell influence an athlete's performance during the clean. [29] To our knowledge, there is no current research on the influence of different weight plates on the bench press.

Methods

Subjects

Fourteen subjects, 12 males and 2 females, were recruited from Appalachian State University and the local Boone area (see Table 1). The inclusion criteria were: subjects between the ages of 18-35, possess at least one year of bench press experience, and exhibit 1RM of at least 45.45 kg (100 lb) on the bench press. The exclusion criteria were: a history of upper extremity injury in the past 6 months that changed their activity level for more than 24 hours, a history of an upper arm traumatic fracture, were pregnant, and/or had a pacemaker/automated defibrillator. The participants were informed of all potential risks involved and signed a written consent prior to participating in the study. Before data collection started, the study was approved by the Institutional Review Board at Appalachian State University. One subject dropped out of the study before the 2nd session due to a shoulder injury outside this study. Due to errors in data collection, further kinetic analysis could not be performed on two subjects' data, while errors during EMG collection removed muscle activation data for another three subjects.

Age (years)	Height (m)	Mass (kg)	Bench Press Exp.(years)
21.21 ± 1.97	1.77 ± .094	84.61 ± 14.91	4.14 ± 1.51

Table 1: Subject Information (Mean ± Standard Deviation)

Covid-19 Protocol

All subjects and researchers were required to wear a facemask during data collection. Before each subject arrived, all researchers were asked if they had any symptoms related to Covid-19 before they entered the lab space and were unable to participate in any data collection if they reported any symptoms. Researchers would then apply hand sanitizer and wiped down all surfaces and equipment with sanitizing solution. Once the subject arrived, they filled out a Covid-19 survey form and if they answered yes to any of the questions they were rescheduled when they no longer had any symptoms. After the subject left the laboratory, all surfaces were wiped down with sanitizing wipes.

Equipment

The bumper plates used in this study were *Sorinex* Recon Lite Bumper Plates (see Table 2). The standard plates were cast irons plates branded USA Olympic (see Table 2). The same standard Olympic barbell was used for all sessions.

Type of Plate	Mass (kg)	Weight (lb)	Diameter (m)	Thickness (m)
Bumper	20.45	45.0	0.451	0.095
Bumper	15.91	35.0	0.451	0.079
Bumper	11.63	25.0	0.451	0.057
Bumper	4.54	10.0	0.451	0.035
Standard	20.45	45.0	0.442	0.030
Standard	15.91	35.0	0.360	0.031
Standard	11.63	25.0	0.271	0.033
Standard	4.54	10.0	0.228	0.017
Standard	2.27	5.0	0.200	0.011
Standard	1.14	2.5	0.161	0.008
Thick Standard	4.54	10.0	0.204	0.021

Table 2: Plate Characteristics

Study Design

The testing was divided into three sessions with each session separated by at least one week. The subjects were asked not to perform any upper body exercises seventy-two hours prior to each session. All the testing sessions occurred at the Biomechanics Laboratory in Levine Hall at Appalachian State University. For all three sessions, grip width was standardized to 150% of the subject's bi-acromial distance. In the first session, the subject's maximal bench press strength was assessed through a 1RM testing protocol utilizing standard plates and a standard barbell. The 1RM testing followed the 1RM guidelines set by the NSCA. During sessions two and three, participants were randomized between performing the bench press using either standard or bumper plates. The participants were blinded to whether they were lifting bumper plates or standard, but participants were informed of the exact load they were lifting during each lift. The participants performed three trials of bench press at 70%, 80%, and 90% of their 1RM. A Certified Strength and Conditioning Coach supervised all sessions.

Session 1 (Maximal Strength Testing)

Before the 1RM testing, the subjects filled out a questionnaire detailing their age, years of bench press experience, hand dominance, and estimated their 1RM. The subject's height, weight, and bi-acromial distance were measured and recorded.

The bench press one repetition (1RM) was tested using the guidelines set forth by the National Strength and Conditioning Association. [1] The warm-up protocol consisted of a load based on the subject's self-reported 1RM which allowed the subjects to easily perform 5-10 repetitions followed by a one-minute rest period. Then, the load was increased by 10-20 pounds to allow for 3-5 repetitions. The participant then rested for two minutes. The load was further increased to a weight the participant was able to perform 1-3 repetitions and then was given a three-minute rest period. The load was then further increased by 5-10% and the subject attempted a 1RM repetition. If successful, the previous step was repeated until the subject could no longer successfully complete a repetition. The load of the last successfully completed repetition was recorded as the subject's 1RM. In order for the repetition to be considered successful, the subject needed to maintain a 5-point contact position, lower the bar completely to the chest, and return the bar to starting position with the elbows fully extended. The 5-point contact position consists of a participant keeping their shoulders and buttocks in contact with the bench and the feet in contact with the ground during the entire lift.

Sessions 2 and 3

Sessions two and three, with randomized order, consisted of performing the bench press with either bumper plates or standard plates. In order to blind the subject to the type of plate, a large cardboard box attached to the barbell (Figure 4) was utilized to blind the subjects to the type of weight plate, the weight trees were covered with a sheet, and the subject was escorted to a separate room while each load was being changed. The subject performed three warm up sets of the bench press: 1x5 60%, 1x5 65%, and 1x5 70%. After the warm-up sets, the subject was fitted with the reflective markers and wireless EMG sensors. Then, the subject performed two 5 s maximal isometric bench repetitions at supramaximal load (200% 1RM) to prevent bar displacement to generate maximal EMG values for later EMG data normalization. For data collection, the subject performed three sets of the bench press with five minutes of rest between each set. The number of repetitions for each set was determined by the common ranges for the percentage of 1RM. The sets consisted of 8 repetitions at 70%, 4 repetitions at 80%, and 2 repetitions at 90% of 1RM. All loads were calculated using the subject's tested 1RM and were rounded to the nearest 2.72 kg (5 lb) increment. The loads were created using the least total number of plates possible, and 2.72 kg (5 lb) and 1.14 kg (2.5 lb) standard plates was used for both bumper and standard plate loads when needed. Due to budget constraints only one set of 4.54 kg (10 lb) bumper plates were purchased. For any load that required a second 4.54 kg plate, the "thick" 4.54 kg standard plate was used as the second 4.54 kg plate.

Kinematic and Kinetic Data Recording

To measure arm kinematic and kinetic data, subjects were fitted with retro-reflective markers on selected anatomical bony landmarks based on previous studies. [3,13,41,42]

Figure 4. Bench setup with blinding boxes attached

The reflective landmarks were placed bilaterally on the acromion process, the midpoint between the acromion process and the medial epicondyle of the elbow on the anterior surface of the upper arm, the lateral epicondyle of the elbow, the medial epicondyle of the elbow, the midpoint between the lateral epicondyle and radial styloid process on the dorsal surface of the forearm, the radial styloid process, the ulnar styloid process, and third metacarpal bone. [16] A final reflective marker was placed two finger widths inferiorly from the jugular notch on the sternum. Barbell kinematic and kinetic data were measured by placing two retro-reflective markers directly opposite each other next to the edge of each sleeve on the inside shaft of the barbell, and a reflective marker placed in the outside center of each sleeve of the barbell. Three-dimensional data recording and analysis was performed by using an 8 camera VICON motion analysis system (Oxford Metric, Oxford, UK). From the data collected, 2-dimensional kinetic and kinematic variables were calculated by using projections of 3-dimensional data in the plane of interest. Marker data were low-pass filtered using the modified technique of Fink and colleagues up to a frequency of 6 Hz and used to calculate joint kinematics at the wrist, elbow and shoulder. [43] The effect of load was including by estimating the external force associated with each hand due to half of each lifted weight. Once joint kinematics and the external force due to the load was calculated, inverse dynamics was used to estimate joint moments associated with each lift. Average and peak moments, as well as impulse over each repetition was calculated. Variables that were used to test the hypothesis specifically were: average time under load per repetition, average total work per repetition, average integrated EMG per repetition, average peak/average/impulse moments (wrist/elbow/shoulder) per repetition.

Electromyography

Electromyography data was collected on the pectoralis major, anterior deltoids, and triceps brachii. EMG electrodes (Delsys, Natick, USA, 27x37x15 mm dimension with 4, 5x1mm contact points; gain=909, bandwidth frequency=20-450 Hz, common mode rejection ratio= 85 dB; sampling=1000/sec) for the anterior deltoids and triceps brachii were placed based on standardized protocols as prescribed from SENIAM (SENIAM.org). EMG electrodes for the pectoralis major were placed according to protocols from Cram. [44] To normalize sEMG values, all participants performed two 5 s maximal isometric bench repetitions at supramaximal load to prevent bar displacement. During the maximal isometric test, the participant's elbows and shoulders were at 90 degrees flexion and upper arms were parallel to the ground. The average peak sEMG of each muscle was used for analysis. The MVC EMG data was filtered with a bandpass filter at 20 and 400 Hz, full wave rectified, and low pass filter at 10 Hz. Finally, the maximum values were calculated. For each trial, the collected EMG data were also filtered with a bandpass filter at 20 and 400 Hz, full wave rectified, and low pass filtered at 10 Hz. The results were integrated between intervals (duration of each repetition) and divided by maximum MVC results to get a normalized EMG value based on the effort throughout each repetition. Average peak EMG values per repetition at each load were compared across different conditions.

Statistics

All statistical analysis was performed in SSPS software version 27.0 (SPSS Inc., Chicago, IL*)* and presented as means and standard deviations. Two-way (2 × 3) repeated measures analysis of variance (ANOVA) was performed to assess differences in TUT (Plate Type x Weight), TW (Plate Type x Weight), and three-way (2 × 3 × 3) repeated measures ANOVA was performed to assess differences in impulse (Plate Type x Weights x Joint), peak joint moment (Plate Type x Weights x Joint), average joint moment (Plate Type x Weights x Joint) and EMG (Plate Type x Weights x Muscle). If sphericity was violated (sphericity ≤ 0.001), a Greenhouse-Geisser correction was used. In the event of significant main or interaction event, *post hoc* comparisons were conducted using the Fisher's LSD method. Statistical Significance was set at $p < .05$. Effect size is shown as partial Eta squared (η^2) and is defined where $0.01 < \eta^2 > 0.06$ represents a small effect, $0.06 < \eta^2 > 0.14$ represents a medium effect, and $\eta^2 > 0.14$ represents a large effect size.

Results

Barbell Kinetics

The participants had a 1RM of 99.51 ± 32.90 kg, and lifted 71.68 ± 23.28 kg at 70% 1RM, 81.29 ± 26.23 kg at 80% 1RM, and 91.61 ± 30.10 kg at 90% 1RM.

TUT and TW

The two-way repeated measures ANOVA indicated a significant Weight main effect ($F(1.076, 11.016) = 51.033$, $p < 0.001$, $\eta^2=0.836$) for TUT. The *post hoc* analysis showed significantly main effect of TUT increasing from 70% to 80% ($p< 0.001$), 70% to 90% ($p< 0.001$), and 80% to 90% ($p< 0.001$).TW had a statistically significant Weight main effect ($F(1.050, 10.50) = 55.451$, $p < 0.001$, $\eta^2=0.121$). The *post hoc* analysis showed significant increase in TW as weight increased from 70% to 80% ($p< 0.001$), 70% to 90% ($p< 0.001$), and 80% to 90% ($p< 0.001$).***Joint Kinetics***

Average joint moment had a statistically significant Weight x Joint interaction effect ($F(4, 40) =60.744$, $p < 0.001$, $\eta^2=0.859$) (Figure 5). *Post hoc* analysis showed the average ulnar deviation moment increased significantly as weight increased from 70% to 80% ($p < 0.001$)., 70% to 90% ($p < 0.001$), and 80% to 90% ($p < 0.001$). However, there was no significant differences in average joint moment from 70% to 80% ($p = 0.678$), 70% to 90% ($p=0.555$), and 80% to 90% ($p < 0.719$) at the elbow joint. At the shoulder joint, the average horizontal adduction moment significantly increased as weight increased from 70% to 80% ($p< 0.001$), 70% to 90% ($p< 0.001$), and 80% to 90% ($p< 0.001$). *Post hoc* analysis additionally indicated the average joint moment was significantly larger at the shoulder compared to the elbow at 70% ($p < 0.001$), 80% ($p < 0.001$), and 90% ($p < 0.001$). The shoulder also had a significantly larger average joint moment than the wrist at 70% ($p < 0.001$), 80% ($p < 0.001$), and 90% ($p < 0.001$). There was no significant difference between the average joint moment between the elbow and wrist at ($p = 0.166$), 80% ($p = 0.138$), and 90% ($p = 0.108$). Furthermore, average joint moment had a significant Plates x Weights interaction effect ($F (2, 20) = 5.358$, $p = 0.017$, $\eta^2 = 0.349$). However, *post hoc* analysis did not show a significant difference between bumper and standard plates at 70% ($p = 0.949$), 80% ($p = 0.960$), and 90% ($p = 0.101$). Average joint moment significantly increased for bumper plates as weight increased from 70% to 80% ($p < 0.001$), 70% to 90% ($p = 0.002$), and 80% to 90% ($p = 0.034$). Average joint moment significantly increased as well for standard plate as weight increased from 70% to 80% ($p = 0.009$), 70% to 90% ($p < 0.001$), and 80% to 90% ($p = 0.003$).

Impulse exhibited similar results to average joint moment after a three-way repeated measures ANOVA displayed a significant Weight x Joint interaction effect ($F (4, 40) = 44.896$, $p < 0.001$, $\eta^2 = 0.818$). *Post hoc* analysis demonstrated shoulder had a significantly larger impulse than the elbow (($p < 0.001$) and the wrist ($p < 0.001$). There was no significant difference in impulse between the wrist and elbow ($p = 0.103$). Analysis also revealed there was a significant Plates x Weight interaction effect ($F (2, 20) = 4.025$, $p = 0.034$, $\eta^2 = 0.287$), but post hoc analysis showed no significance between bumper and standard plates at 70% ($p = 0.820$), 80% ($p = 0.951$), and 90% ($p = 0.091$).

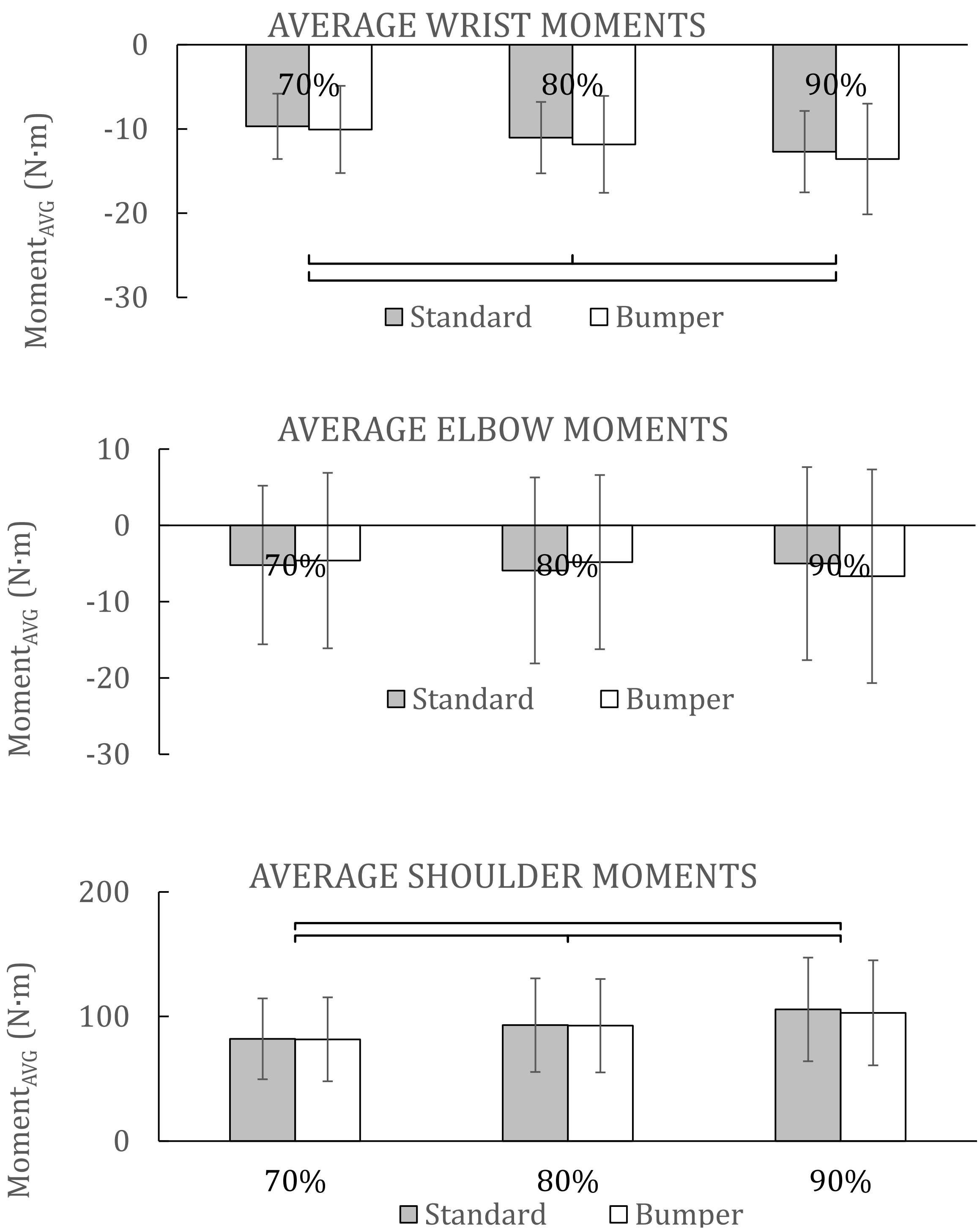

Figure 5. Average joint moments at the wrist, elbow and shoulder. Significant differences ($p < 0.05$) between loads (70%, 80%, 90%) shown with line connecting loads below (⊔) or above (⊓). Negative wrist moment indicates ulnar deviation. Negative elbow moment indicates extension. Positive shoulder moment indicates horizontal adduction.

Impulse significantly increased for standard plates as weight increased from 70% to 80% ($p = 0.004$), 70% to 90% ($p <0.001$), and 80% to 90% ($p <0.001$). Impulse also significantly increased as well for bumper plates as weight increased from 70% to 80% ($p = 0.001$), 70% to 90% ($p = 0.002$), and 80% to 90% ($p = 0.003$).

Peak joint moment demonstrated parallel results to average joint moment as analysis showed there was a significant Weight x Joint interaction effect (F (1.628, 16.280) = 33.74, p,.0010.000, η^2=0.770). *Post hoc* analysis displayed the peak joint moment for ulnar deviation significantly increased as weight increased from 70% to 80% ($p <0.001$), 70% to 90% ($p <0.001$), and 80% to 90% ($p <0.001$). Peak joint moment for elbow extension also significantly increased at the elbow joint as weight increased from 70% to 80% ($p = 0.011$), 70% to 90% ($p = 0.004$), and 80% to 90% ($p = 0.019$). The peak joint moment for horizontal adduction significantly increased at the shoulder joint as weight increased from 70% to 80% ($p <0.001$), 70% to 90% ($p <0.001$), and 80% to 90% ($p = 0.003$).

Electromyography

The three-way repeated measures ANOVA showed there was a significant Weight main effect (F (2, 14) = 65.967, $p < 0.001$, η^2=0.904) for EMG. *Post hoc* analysis showed there was significant increase in EMG as weight increased from 70% to 80% ($p < 0.001$), 70% to 90% ($p < 0.001$), and 80% to 90% ($p < 0.001$). There were no significant differences between the different plates in the EMG measures.

Discussion

The aim of this study was to identify any possible biomechanical differences during the bench press when using either bumper plates or standard plates. The specific variables of interest were related to the kinetics of the movement (TUT, TW, average joint moment, impulse, peak joint moment), as well as muscle activation. The main finding of the study was that there were no significant kinetic differences or muscle activation differences when using bumper or standard plates during the bench press. Therefore, our hypotheses were not supported.

Many of the measures we calculated are similar to previous studies that have measured other aspects of the bench press exercise. For example, this study TUT had a mean time per rep of 2.18 s for 70% and 2.39 s for 80%, which is similar to the estimated per rep time of 1.90 s for 70% and 2.04 s for 80% from a previous study comparing TUT for the bench press under different weights and repetitions. [45] In the present study, TUT and TW were not significantly different when using bumper or standard plates, but both TUT and TW increased significantly as the weight increased on the bar. The average joint moment for ulnar deviation and horizontal shoulder adduction increased as weight increased, but average joint moments at the elbow did not change between the differing weights. The shoulder had a larger average joint moment than both the wrist and elbow, and the elbow and wrist did not have a significantly different average joint moment. The shoulder horizontal abduction (114.87 ± 49.65 Nm) and elbow extension peak moments (37.70 ± 13.50 Nm) were similar to shoulder horizontal abduction (123.0 ± 48.50 N) and elbow extension peak moments (22.15 ± 8.35 Nm) in a study by Mausehund et al. at 80% of 1RM. [3] Parallel to a previous study, peak moments for shoulder abduction, elbow extension , and ulnar deviation all significantly increased with an increase in weight, [46] but did not differ between plate types. Impulse did not differ between plate types but did increase as weight increased. EMG activity of the anterior deltoid, triceps brachii, and pectoralis major all increased as weight increased which is similar to results found in a study on the effect of weight on the bench press by Król and Gołaś. [32]

There are a few potential reasons why our main hypotheses, finding differences between the two different types of plates, were not supported. The main reason that we did not find differences in the kinetics and muscle activation in the prime movers when using bumper or standard plates during the bench press was that weight on the bar is the main determining factor for the kinetics and muscle activation of the bench press. For instance, a few previous studies have revealed there is no difference in muscle activation in the prime movers during stable and unstable conditions during the bench press. [47,48] Although, one study suggested the stabilizing muscles become more active to help control the barbell during an unstable condition. [48] Moreover, people perceive the sensations of an object from the magnitude of the external forces acting on the object, so the participant's mind reacts mainly to lifting a larger force of gravity of an object compared to the other forces acting on the object. [49] Even though it is not a part of the finding of this study, participants filled out a survey asking their rating of perceived exertion (RPE) on scale of 1-10. RPE for bumper plates was 7.08 ± 1.32 and RPE for standard plates was 7.31 ± 1.03, but no significant difference was found for RPE using a Chi-Squared test (X^2 (4,N=26)=2.311, p=0.679). We further hypothesized that the increased thickness of the bumper plates would affect moment of inertia (MOI) of the barbell which could alter the join kinetics of the barbell during the bench press. The MOI of the barbell system can be found by summing the MOI of each component of the barbell and the plates. Therefore, the thicker width of the bumper plates would have a greater impact on increasing MOI of the barbell than a standard plate. The larger the MOI of an object the greater its resistance to change in angular velocity from a fixed axis of rotation. [23] We thought this increased resistance to angular velocity would increase the moment and impulse at the joints as the participant controls the barbell throughout the bench press. One reason we might not have seen difference is there were not enough bumper plates on the bar to create a significant difference between the distance of the center of mass of bumper and standard plates to significantly increase the MOI. Since the bench press is a very symmetric and controlled movement, the angular accelerations of the lift might not have been large enough for the increased MOI to affect amount of resistance to increase the joint moment and/or joint impulse. Furthermore, our protocol might not have fatigued the muscles enough for the increased MOI to overcome the muscles' ability to control the barbell. Other studies looking at upper extremity stability have used rapid movements, a larger number of repetitions, working to a fatigued state, and working to failure. [13,16,36,37] One study found as fatigue increased the moment and force significantly increased on the elbow joint. [13] Another study demonstrated as fatigue increased the stability of the upper extremity decreased and increased the yaw and pitch perturbation of the barbell.[16]

Since the bumper plates were up to three times as thick as standard plates, it was thought that this would affect the amount of bar deformation. This increase in deformation would the cause the bar loaded with bumper plates to travel a farther distance and thus would affect TW and TUL. [17,18,23–25,29] Previous studies and anecdotal evidence have shown the impact of bar deformation on pulling lifts such as the deadlift and clean. One study compared several different barbells and found the amount of deformation from the end of the barbell to the center of the barbell was 1.37 ± 0.16 cm at 70 kg, 2.24 ± 0.19 cm at 120 kg, 3.18 ± 0.26 cm at 170 kg, and 4.01 ± 0.19 cm at 220 kg. [17] During more dynamic lifts such as clean, this amount of deformation can increase to 4 to 6 cm. [29] The participants in this study lifted 71.67 ± 23.28kg at 70% 1RM, 81.29 ± 26.22 kg at 80% 1RM, and 91.60 ± 30.09 kg at 90% 1RM. These weights would put the bar deformation in between 1.4 and 2.2 cm of bar deformation for the participants in this study. This amount of deformation might not have been enough to elicit enough increase of distance to increase TUT or TW. The exact amount of bar deformation to have a significant impact on TW and TUL is unclear, but a cambered bar with a depth of 9 cm has been shown to significantly increase the distance the bar traveled and therefore increased the TW and TUL. [29] Subjects with a large 1RM would have more plates on the bar during their repetitions which might increase the depth of deformation enough between plate types gain a significant difference in barbell path distance. Additionally, the specific region where bar deformation occurs should be considered. The amount of bar deformation at the center and ends of the bar can be quantified

with equations for a beam with ends overhanging supports with two equal loads applied at symmetrical locations. [18] The equation for the deformation at the ends of bar is $\frac{Wc^2}{6EI}(2c + 3l)$ and the equation for deformation at the center of the bar between the hands is $-\frac{Wcl^2}{8EI}$. By comparing the two equations the amount of deformation at the ends of the bar would be larger than at the center of the bar. Thus, bar deformation at the ends is more advantageous in pulling lifts such as deadlifts and Olympic lifts because it shortens the distance the hands need to be pulled to complete the lift. Anecdotal evidence asserts bumper plates can increase a deadlift by 27.27 kg (60 lb) compared to using standard plates. [24,25] Olympic lifters also tend to prefer bars with more deformation. [17,29]

Another possible explanation for finding no differences between bumper and standard plates is related to human perception. One study found a 10 cm difference in center of gravity is around the distance a participant needs to sense a significant difference in the location of center mass. [7] For the center of mass to have a difference of around 10 cm, the minimum weight is 125 kg (275 lb), and the participants in this study in the highest repetition level of 90% IRM only lifted 91.61 ± 30.10 kg. Moreover, people can easily perceive the MOI of object, they often lack the vocabulary to effectively communicate the sensation. [22] The participants in this study might have only used standard plates in the past and did not know how to describe the difference in feel of barbell with bumper plates. A second part of the survey, which asked for the RPE for each session, asked participants which plate they lifted that day. To analyze the reliability of the plate survey, a reliability analysis conducted in SPSS calculated the plate survey had an intraclass correlation (ICC (2, 1) = 0.710). The ICC was then used to calculate the standard error of measurement (SEM) which was 0.27. The SEM was used to calculate the minimal difference (MD) of 0.75 or 5%. This MD defines the statistical minimal difference between the expected outcomes of a correct guess (50%) and the percentage of people that actually correctly answered without guessing, ergo any survey with correct answers of at least 5% over 50% would not be due to participants simply guessing which plate type they lifted. During the second session 54% of the subjects in second session where correct in the type of plate they used. Since the survey was only over 4% of the expected outcome of 50%, there is chance this survey was only people guessing which type of plate they lifted that day. However after the third session, 62% of subjects circled the correct type of weight they used that day. The increase of 12% over the expected 50% for a random guess, shows improvement from the second session to the third session. This improvement might demonstrate participants being able to start to recognize the difference between the two types of plates and be able to accurately describe the type of weight plate with more sessions. Besides lacking a vocabulary to describe MOI, people need a least a difference of 30 to 40% to detect a difference of MOI in the same object compared to only 2 to 3% difference to detect a difference in weight. [22]

One of the interesting findings of this studies was that there was no difference in average joint moment at the elbow, but there was a difference in peak joint moment at the elbow as weight increased. This moment was an extension moment. This finding could help explain the role of the triceps brachii through the ascent (concentric) phase of the bench press. To start accelerating the barbell off the chest, the triceps brachii reach a peak moment to start the ascent phase of the barbell. The body quickly transitions to the deltoids and pectoralis major as the major contributors to creating the upward force necessary to push the barbell upwards. [32] As the deltoids and pectoralis major are the creating most of the upward force, the moment arm and force from the triceps at the elbows decreases during the rest of the upward phase. [32] Thus, this indicated why there is a significant increase in peak moment for elbow extension and muscle activity in the triceps brachii while not having a significant difference in average joint moment. On the other hand, this finding could be explained by the fact that the elbow does not produce an extension moment throughout the movement exclusively. For some subjects, the elbow moment varied considerably, with a flexion moment being produced at the end of the upward phase and start of the downward phase. The flexion and extension moments would cancel each other out in during average joint moment calculation but would not have the same effect on peak moment calculations.

Our study did have a few potential limitations. There have not been to our knowledge any previous studies looking at the difference between bumper and standard plates in any powerlift. Since this was the case, we based our number of subjects on previous studies looking at different aspects of the bench press. [5,10,11,13,16,41] The minimum bench press was set at 45.45 kg (100 lb) in order to be cover a wide range of lifters, but future studies should look at more elite bench press athletes with a minimum 1RM of 159.1 kg (350 lb) to examine if there is enough of an increase in both bar deformation and MOI to significantly affect the kinetics of the bench press. A third limitation of the study was a couple of the participants reported they could hear the sound of the cast iron plates rub against each other as they performed repetitions even though many steps were taken to help blind the participant from the plate type. Finally, muscle activation in stabilizing muscles should be monitored to see if there is any increased muscle activation.

Practical Applications

The main finding of this study might be helpful for recreational lifters, personal trainers, gym owners, and strength and conditioning coaches. When bench pressing, a lifter can choose to lift with bumper or standard plates without affecting TW,TUT, average joint moment, peak joint moment, and muscle activation.

References

1. Haff G, Triplett NT, National Strength & Conditioning Association (U.S.), eds. *Essentials of strength training and conditioning*. Fourth edition. Human Kinetics; 2016.

2. Jakiela J, Caterisano DA, Hutchison DR, Moss DR. Comparison of muscle activity between the Tsunami Barbell™ and an Olympic barbell. Published online 2013:1.

3. Mausehund L, Werkhausen A, Bartsch J, Krosshaug T. Understanding bench press biomechanics—The necessity of measuring lateral barbell orces. *J Strength Cond Res*. 2021;Publish Ahead of Print. doi:10.1519/JSC.0000000000003948

4. Krzysztofik M, Jarosz J, Matykiewicz P, et al. A comparison of muscle activity of the dominant and non-dominant side of the body during low versus high loaded bench press exercise performed to muscular failure. *J Electromyogr Kinesiol*. 2021;56:102513. doi:10.1016/j.jelekin.2020.102513

5. Krzysztofik M, Golas A, Wilk M, Stastny P, Lockie RG, Zajac A. A comparison of muscle activity between the cambered and standard bar during the bench press Exercise. *Front Physiol*. 2020;11:875. doi:10.3389/fphys.2020.00875

6. Stastny P, Gołaś A, Blazek D, et al. A systematic review of surface electromyography analyses of the bench press movement task. *PloS One*. 2017;12(2):e0171632. doi:10.1371/journal.pone.0171632

7. Piper TJ, Radlo SJ, Smith TJ, Woodward RW. dynamic balance abilities of collegiate men for the bench press. *J Strength Cond Res*. 2012;26(12):3225-3229. doi:10.1519/JSC.0b013e318248d789

8. Saeterbakken AH, Mo DA, Scott S, Andersen V. The effects of bench press variations in competitive athletes on muscle activity and performance. *J Hum Kinet*. 2017;57(1):61-71. doi:10.1515/hukin-2017-0047

9. Wagner LL, Evans SA, Weir JP, Housh TJ, Johnson GO. The effect of grip width on bench press performance. *Int J Sport Biomech*. 1992;8(1):1-10. doi:10.1123/ijsb.8.1.1

10. Krzysztofik M, Zajac A, Żmijewski P, Wilk M. Can the cambered bar enhance acute performance in the bench press exercise? *Front Physiol*. 2020;11:577400. doi:10.3389/fphys.2020.577400

11. Ghigiarelli JJ, Pelton LM, Gonzalez AM, Fulop AM, Gee JY, Sell KM. Effects of a 6-week bench press program using the Freak Bar in a sample of collegiate club powerlifters. *J Strength Cond Res*. 2018;32(4):938-949. doi:10.1519/JSC.0000000000002430

12. Duffey MJ, Challis JH. Fatigue Effects on Bar Kinematics During the Bench Press. *J Strength Cond Res*. 2007;21(2):556. doi:10.1519/R-19885.1

13. Huang YP, Chou YL, Chen FC, Wang RT, Huang MJ, Chou PPH. Elbow Joint Fatigue and Bench-Press Training. *J Athl Train*. 2014;49(3):317-321. doi:10.4085/1062-6050-49.1.05

14. McBride JM, McCaulley GO, Cormie P, Nuzzo JL, Cavill MJ, Triplett NT. Comparison of Methods to Quantify Volume During Resistance Exercise. *J Strength Cond Res*. 2009;23(1):106-110. doi:10.1519/JSC.0b013e31818efdfe

15. Williams DM, Sharma S, Bilodeau M. Neuromuscular fatigue of elbow flexor muscles of dominant and non-dominant arms in healthy humans. *J Electromyogr Kinesiol*. 2002;12(4):287-294. doi:10.1016/S1050-6411(02)00024-X

16. Chou PH. Effects of Fatigue on Stability of Upper Extremity During Bench-press Exercise. *J Med Biol Eng*. 2012;32(6):437. doi:10.5405/jmbe.973

17. Chiu LZF. Mechanical Properties of Weightlifting Bars. *J Strength Cond Res*. 2010;24(9):2390-2399. doi:10.1519/JSC.0b013e3181ecd359

18. Oberg E, Jones FD, Horton HL. *Machinery's Handbook: A Reference Book for the Mechanical Engineer, Draftsman, Toolmaker and Machinist*. 21. ed., 4. print. Industrial Press; 1981.

19. Rogue Olympic Plates. Rogue Fitness. Accessed March 19, 2021. https://www.roguefitness.com/rogue-olympic-plates

20. Rogue Bumper Plates by Hi-Temp. Rogue Fitness. Accessed March 19, 2021. https://www.roguefitness.com/rogue-hi-temp-bumper-plates

21. Recon Lite Bumpers. Sorinex. Accessed March 19, 2021. https://www.sorinex.com/products/recon-lite-bumpers

22. Kreifeldt JG, Morse R. The Moment of Inertia of Common Objects: A Prediction Equation and Its Relevance to Design. :5.

23. Ling SJ, Sanny J, Moebs W, OpenStax College, Rice University. *University Physics*.; 2016.

24. Materials Science of the Barbell | Andrew Lewis. Starting Strength. Accessed March 5, 2021. https://startingstrength.com/article/materials-science-of-the-barbell

25. The Science of Strongman: The Curious Case of the Bumper Plate PR - Starting Strongman. Accessed March 5, 2021. https://startingstrongman.com/2017/12/09/the-science-of-strongman-the-curious-case-of-the-bumper-plate-pr/

26. Judge LW, Petersen JC, Bellar DM, Craig BW, Cottingham MP, Gilreath EL. The current state of NCAA Division I collegiate strength facilities: size, equipment, budget, staffing, and football status.

27. Forde RD and P. The crippling impact of schools cutting NCAA sports teams. Sports Illustrated. Accessed March 16, 2021. https://www.si.com/college/2020/06/11/college-sports-program-cuts-ncaa-olympics

28. DIVISION III 2020-21 facts and figures. NCAA.org - The Official Site of the NCAA. Published September 23, 2020. Accessed March 15, 2021. https://ncaaorg.s3.amazonaws.com/about/d3/2018-19D3_FactandFigures.pdf

29. Chiu LZF, Schilling BK, Fry AC, Salem GJ. The influence of deformation on barbell mechanics during the clean pull. *Sports Biomech*. 2008;7(2):260-273. doi:10.1080/14763140701841795

30. Kreifeldt J, Chuang M. Moment of inertia: psychophysical study of an overlooked sensation. *Science*. 1979;206(4418):588-590. doi:10.1126/science.493965

31. Lincir, Tom. Why Olympic bars cost what they cost. Published online Spring 2001. Accessed April 11, 2021. https://www.ivankobarbell.com/press/

32. Król H, Gołaś A. Effect of barbell weight on the structure of the flat bench press. *J Strength Cond Res*. 2017;31(5):1321-1337. doi:10.1519/JSC.0000000000001816

33. Elliott BC, Wilson GJ, Kerr GK. A biomechanical analysis of the sticking region in the bench press: *Med Sci Sports Exerc*. 1989;21(4):450-462. doi:10.1249/00005768-198908000-00018

34. Duffey MJ, Challis JH. Vertical and lateral forces applied to the bar during the bench press in novice lifters. *J Strength Cond Res*. 2011;25(9):2442-2447. doi:10.1519/JSC.0b013e3182281939

35. Škarabot J, Cronin N, Strojnik V, Avela J. Bilateral deficit in maximal force production. *Eur J Appl Physiol*. 2016;116(11-12):2057-2084. doi:10.1007/s00421-016-3458-z

36. Bagesteiro LB, Sainburg RL. Handedness: Dominant arm advantages in control of limb dynamics. *J Neurophysiol*. 2002;88(5):2408-2421. doi:10.1152/jn.00901.2001

37. Bagesteiro LB, Sainburg RL. Nondominant arm advantages in load compensation during rapid elbow joint movements. *J Neurophysiol*. 2003;90(3):1503-1513. doi:10.1152/jn.00189.2003

38. Sainburg R. Evidence for a dynamic-dominance hypothesis of handedness. *Exp Brain Res*. 2002;142(2):241-258. doi:10.1007/s00221-001-0913-8

39. Howard JD, Enoka RM. Maximum bilateral contractions are modified by neurally mediated interlimb effects. *J Appl Physiol*. 1991;70(1):306-316. doi:10.1152/jappl.1991.70.1.306

40. Rogue Ohio Deadlift Bar - Black Zinc. Rogue Fitness. Accessed April 30, 2021. https://www.roguefitness.com/rogue-ohio-deadlift-bar-black-zinc

41. Larsen S, Gomo O, van den Tillaar R. A biomechanical analysis of wide, medium, and narrow grip width effects on kinematics, horizontal kinetics, and muscle activity on the sticking region in recreationally trained males during 1-RM bench pressing. *Front Sports Act Living*. 2021;2:637066. doi:10.3389/fspor.2020.637066

42. Wu G, Roy PV, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *J Biomech*. Published online 2005:12.

43. Fink C, Preiß R, Schöllhorn WI. How to find the optimal cutoff frequency for filtering kinematic data. *ISBS - Conf Proc Arch*. Published online 1998. Accessed March 16, 2022. https://ojs.ub.uni-konstanz.de/cpa/article/view/1225

44. Cram JR, Kasman GS, Holtz J. Introduction to surface electromyograph*y*. Aspen Publishers; 1998.

45. da Silva JB, Lima VP, Paz GA, et al. Determination and comparison of time under tension required to perform 8, 10 and 12-RM loads in the bench press exercise. *Biomed Hum Kinet*. 2016;8(1):153-158. doi:10.1515/bhk-2016-0022

46. Schütz P, Zimmer P, Zeidler F, et al. Chest exercises: Movement and oading of shoulder, elbow and wrist joints. *Sports*. 2022;10(2):19. doi:10.3390/sports10020019

47. Goodman CA, Pearce AJ, Nicholes CJ, Gatt BM, Fairweather IH. No difference in 1RM strength and muscle activation during the barbell chest press on a stable and unstable surface. *J Strength Cond Res*. 2008;22(1):88-94. doi:10.1519/JSC.0b013e31815ef6b3

48. Dunnick DD, Brown LE, Coburn JW, Lynn SK, Barillas SR. Bench press upper-body muscle activation between stable and unstable loads. *J Strength Cond Res*. 2015;29(12):3279-3283. doi:10.1519/JSC.0000000000001198

49. Greer KL. Gravitational and inertial effects of mass on the perceived heaviness of objects. *Bull Psychon Soc*. 1989;27(1):18-20. doi:10.3758/BF03329885

Vita

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