MANIPULATING IMPLEMENT WEIGHT DURING WARM UP

TO IMPROVE SHOT PUT PERFORMANCE

by

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ABSTRACT

The purpose of this study was to investigate the use of overweight and underweight implements impacts on shot putting performance along with technical and physiological changes. Ten collegiate shot putters participated in this study (6 male, 4 female). Each participant completed 3 non consecutive days of data collection. Each day consisted of 3 warm up throws followed by 6 maximal effort regulation weighted throws. Warm up throws consisted of one of three conditions: (1) overweight (2) underweight or (3) regulation. In agreement with prior literature on post-activation potentiation (PAP), those who threw with overweight implements showed significant increases in performance. No changes in critical factor kinematics or ground reaction force measures were affected by warm up weight. Results of this study conclude that using a heavy implement during warmups is a functional way to improve performance, however more research is needed to further uncover the underlying mechanisms.

CHAPTER ONE

INTRODUCTION

The sport of shot putting has been contested since the ancient Greek times, once staring as stone throwing. Evolving over the years until it saw its first Olympic Games in 1896. The sport of shot putting has since seen many changes in technique and training interventions with the goal of improving performance. A substantial body of research exists identifying critical factors of performance[1,2,3] or differences between technique[4,5]. However, fewer studies exist identifying training or technical interventions coaches could implement to help improve shot putting performance.

Previous research investigating ways to improve shot putting performance show the use of Post Activation Potentiation (PAP) stimuli to significantly improve performance. PAP is the phenomenon that a muscles contractile history can enhance its subsequent production of force.[6] By inducing a maximal contraction via PAP stimulus you can enhance a muscles ability to recruit motor units and increase contraction speed thus improving force output. Specific movements such as a clean and jerk at 80% of 1 rep maximum or 3 reps of a 20-meter sprint yield significant improvements in subsequent shot put performance.[7,8] This research supports the use of PAP stimuli to increase performance, however, stimuli such as a clean and jerk or 20-meter sprint are not suitable for competition environments.

With the lack of availability to perform certain PAP exercises during competition alternative stimuli has been introduced. One increasingly popular stimulus is the use of overweight and underweight implements in warm ups to induce PAP. Prior research has shown improved performance in over-the-head backward shot throws,[9] and weight throws[10.11] by using overweight implements during warm ups. While these studies clearly highlight a practical application, they lack to address the specific mechanism behind these performance benefits. Specifically, if this improvement in performance following overweight implement use in warm ups is due to an improvement in kinematic factors of technique or a product of the mechanistic properties of PAP.

The purpose of this study was to investigate how manipulating implement weight during warm up affects the kinematics and kinetics of the rotational shot-put throw. We hypothesized that throw distance would increase following a warmup with overweight implements and that increased throw distance would be accompanied by increased ground reaction forces and better performance on critical factors for shot put performance. In this paper, Chapter Two reviews the literature to provide a background for the research. Chapter Three comprises a study to address the following research question and hypothesis:

Research Question

How does manipulating implement weight during warm up affects the kinematics and kinetics of the rotational shot-put throw.

Hypothesis

Throw distance would increase following a warmup with overweight implements and that increased throw distance would be accompanied by increased ground reaction forces and better performance on critical factors of technique.

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CHAPTER TWO

LITERATURE REVIEW

Shot Put

The sport of shot putting has been a contested athletic event since the 1896 Olympic Games. The goal of the sport is to throw the shot as far as possible. Athletes must throw with one hand and keep their elbow above their shoulder, mimicking a bench press "putting" movement. Since ancient times there have been many changes in technique and training methods of the sport due to the increasing knowledge in the field of sports science. Previous research identifies technique, anthropometrics and strength levels all play a large role in overall shot putting performance.[1,2,3,4] This literature review will evaluate specific interventions to help improve shot putting performance by way of both strength and technical performance.

Shot Putting Technique

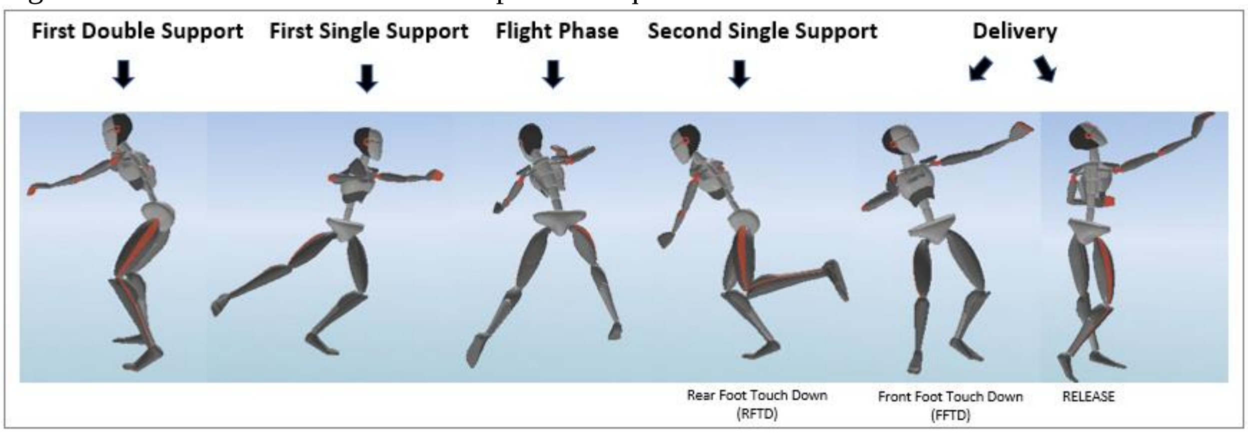
Rotational vs Glide

Two different techniques for throwing the shot put are primarily used today, the linear "glide" technique and the rotational "spin" technique. In the early 1950's the glide was the primary technique used. However, in the early 1970's the rotational style began to pave its way as a new and superior technique.[1] The rotational technique has higher potential for better performances as it allows the athlete to accelerate the shot over a greater distance, thus yielding higher release velocities. However, it is also a more complex technique whose parts must be timed correctly to see the benefits. As such, there may be more room for error or suboptimal performance due to technical inconsistencies.

Phases of the Rotational Technique

The rotational technique consists of five separate but interconnected phases. These phases include first double support, first single support, flight, second single support, and delivery phase (Figure 1). Each Phase is important for the performance of the throw because momentum is transferred through each phase.[6,7] However, of the five, the phases with the largest impact on performance are the flight phase, second single support and delivery phases. Within these three phases there are specific critical factors of technique that can aid in performance.[3]

Figure 1. Phases of the rotational shot-put technique



Critical Technical Factors of the Rotational Shot Put

The number one determining factor of rotational shot putting performance is release velocity.[6,8,9] This is simply due to the physics of a projectile object. Previous studies agree that release height, angle and velocity all play a large role in the displacement of the shot put. However, the ways in which these optimal release parameters should be created has be debated.

One way to increase release velocity is by generating high levels of momentum and torque within the phases of the throw.[1,2,3,6] One specific factor of technique associated with higher release velocities, momentum and torque is having an optimal knee flexion angle during the second single support phase. The optimal knee angle is largely dependent on an athletes strength but ranges from 105-115 degrees.[10] This allows the athlete to turn with the most force and power possible. Thus, leading to a larger amount of force being put into the shot put, ultimately leading to improved performance.

Another factor of technique that has been shown to increase release velocity, momentum and torque is the shoulder and hip separation angles during the second single support phase. Within the preceding flight phase of the rotational technique athletes drive their swing leg to the middle of the ring to generate both momentum and separation. They then land their swing foot into the center of the ring entering the second single support phase; also called Rear Foot Touch Down (RFTD). Shortly after RFTD the second foot will reach to the front of the ring and plant on the ground also called Front Foot Touch Down (FFTD). The Shoulder/Hip separation angles at FFTD has been previously identified to lead to greater improvements in performance.[1,10] These improvements are thought to be products of the greater pretension in the trunk allowing the implement to be accelerated over a larger path. The optimal angles for Shoulder/Hip separation lie between 50-70 degrees however an athlete’s strength and power play a large role in the ability to reach such angles.[10,11]

Lastly, researchers identify pelvis angular velocity during the second single support phase through the release phase to be a large predictor of shot put performance. Once athletes enter the release phase they turn their hip quickly, followed by their torso and ultimately extend and press the shot put out into the sector. The larger values of pelvis angular velocity in the release phase are strongly correlated to the release velocities seen with the shot put itself. Thus, proposing the larger pelvis angular velocities help to increase torque and momentum of the throw, ultimately improving release velocities and performance.[10-13]

Improving these critical factors; knee flexion, shoulder hip separation and pelvis angular velocity, can help to improve torque, force production and momentum thus leading to increases in release velocities. However more ways to improve shotting performance can be seen outside of technique. Many researchers have evaluated the ways in which athlete's anthropometrics and strength profiles can help to enhance performance.

Strength and Conditioning

Strength and conditioning is another area of literature that helps to identify ways in which athletes can improve shot putting performance. Specific factors of muscular strength have been shown to be correlated to improved shot putting performance. However, muscle mass is not the sole predictor of performance. The shot put is an incredibly explosive event that takes less than two seconds. Due to the complexity of the sport, the strength and condition training is equally as complex and intricate.

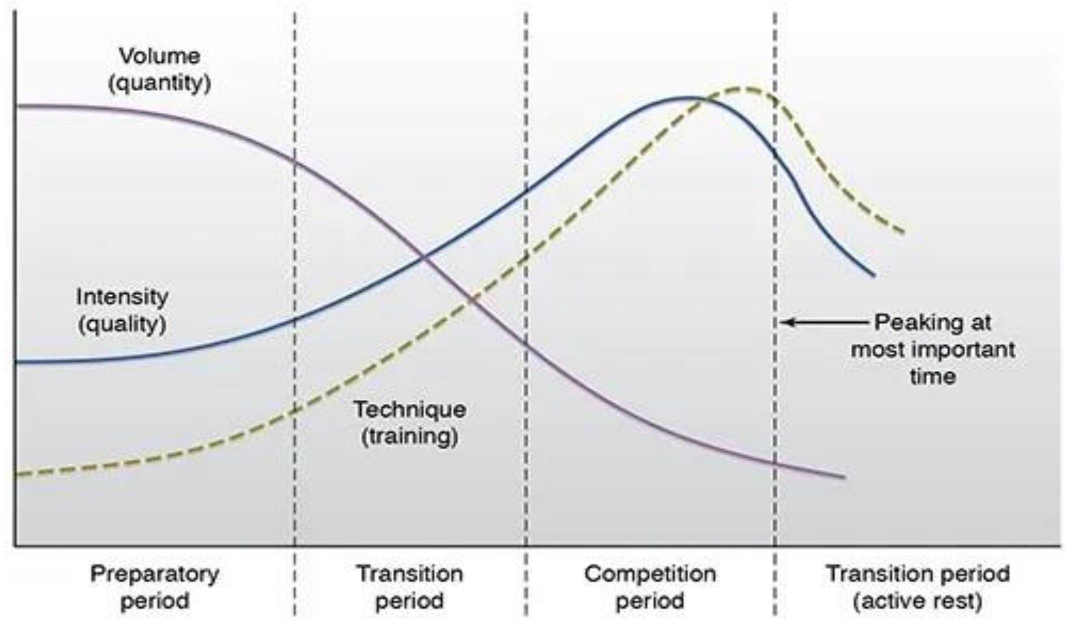
Evaluations of specific strength profiles of athletes show that shot put performance is closely correlated with measures of absolute muscular strength, however, the key to bettering performance is to develop muscular power.[14-17] Literature has elaborated on this by stating that the muscular power of the lower extremities is a better predictor of shot-putting performance than absolute muscular strength.[18,19] Explaining that being able to overcome resistance is highly important, however, overcoming that resistance in the quickest amount of time is the key to improved performance. One study evaluated measures of strength that were most correlated to shot put performance.[2] This study found that the power clean was the most closely related lift to shot put performance compared to both squat and bench press. Similarly in another study, strong correlations were found between a 1RM snatch and shot put performance in well trained throwers.[20] Supporting the idea that power specific lifts may be more correlated to increased shot put performance.

The development of power in technique and power specific lifts is important to the overall performance in the shot put. Muscle activation during the throw itself has become an increasing area of interest.[21,22,23] Studies have shown that shot put performance is dependent on the activation of the vastus laterals and the pectorals major during the delivery phase. Data suggests that the speed of activation of the triceps is correlated with improved performance.[24] Concluding that both the level and speed of activation plays a large role in improving performance.

Further investigation on how to most effectively build power in the weight room has also been done. Specifically evaluating the periodization of training, along with the layout of individual training sessions. In one study the effects of complex strength and power exercised in pairs vs compound strength and power exercises on different days was evaluated. Results show that pairing strength and power exercises on the same days lead to greater increase in 1 RM strength, power, force development and throwing performance.[25] Thus pairing of both power and strength exercises together on the same training days may be a beneficial way to improve performance during a pre-competition period.

More studies have been done evaluating training interventions regarding strength and condition during competition periods. Most researchers agree that when entering the competition period, you begin to lower volume of training while increasing the specificity and intensity of movements[26,30] (Figure 2[30]). In one study looking at peaking shot putters in the competition period they investigated both a peak with heavy (85% 1RM) and light (30% 1RM) loads. Results of this study showed that performance increased in both heavy and light load peaks, however the heavy loads led to greater increases in strength, whole body power and rate of force development.[31,32] These results support the use of heavy stimuli to properly taper and peak athletes. This may be due to the physiological properties of muscle, allowing more muscle activation within the heavy group leading to increased performance on competition days.

Figure 2. Periodization of training: volume, intensity and technique vs. specific period of training.[30]



Post Activation Potentiation

Another area of increasing interest regarding strength and conditioning and muscle physiology is the phenomenon of Post Activation Potentiation (PAP). PAP is the idea that a muscles contractile history can impact its subsequent force production and performance. Literature regarding PAP elaborates that a non-fatiguing muscle contraction at a high load with low duration may enhance the following muscle performance and force production.[33] The reason for the increase in force production of the muscle is thought to be mechanistically caused one of two ways. The first is by phosphorylation of myosin regulatory light chains. This phosphorylation causes actin and myosin to be more sensitive to calcium. As a result, the force of each muscle twitch is increased.[34,35,36] The second explanation is thought to be caused by an increase of synaptic excitation inside the spinal cord. This excitation in the spinal cord then leads to an increase in post-synaptic potentials and the increased capacity of muscle groups to produce force.[37]

Literature has also evaluated the impacts this phenomenon has on differing muscle fiber types, suggesting that type ll muscle fibers are most impacted and affected by PAP stimuli.[35,38,39] Therefore, athletes who compete in high intensity explosive events such as weightlifting, sprinting and throwing may benefit the most from PAP stimuli.[40,41,42] Another factor that may impact an athlete's response to PAP stimuli is their strength levels. Athletes who are stronger tend to have greater responses to PAP stimulation.[43,44] The strength and muscular architecture of an athlete may also play a role in the amount of rest time needed between PAP stimuli and performance of the desired activity.

The sport of track and field has shown specific PAP stimulus to be impactful when improving performance in throwing events. One study looked at shot putting and PAP stimuli including countermovement jumps and 20-m sprinting. Results of this study show that after a standard warm up protocol athletes that completed 3 consecutive countermovement jumps or a bout of 20-m sprinting saw an increase in shot putting performance compared to the control.[45] In a similar study, the effects of a standard warm up was compared to a warmup that was followed by a PAP conditioning activity. Results of this study show that athletes who warmed up with a PAP conditioning activity (clean and jerk at 80% 1RM) showed a significant improvement in shot putting performance.[46] Further evaluation of PAP found that when primed with a 3RM bench press the following shot-putting performance is significantly improved compared to baseline.[47] These studies support the use of PAP stimuli to help increase shot putting performance however, most of these interventions are not suitable to complete in a competition environment. The use of an Olympic lifting bar and weights is not easily accessible to most athletes during a track and field meet. Recent literature has offered the possible stimuli of using overweight and underweight implements to induce PAP during warmups.

Overweight and Underweight Implements

Studies on the weight throw, an indoor throwing event, shows that the use of an overweight implement during warmups significantly improves both high school and collegiate weight throwing performance.[48,49] In another study evaluating overhead back shot-putting the results show that the use of an overweight implement during warmups yielded significantly greater performance compared to baseline.[50] Thus supporting the idea that overweight implements may be a useful stimuli to enhance PAP in throwing events. However, there are currently no studies evaluating their impacts on rotational shot-putting performance.

The use of overweighted and underweighted implements has also been studied to evaluate their impacts on technique and skill enhancement. In baseball, the use of overweight and underweight bats and balls can be used as a form of specific resistance training. Elaborating that overweight implements ate used to induce a force overload and underweight implements are used to induce a speed overload.[51,52,53] Dinu[54]evaluated the effects of throwing a 6kg vs 7.26 kg shot put on technical factors of the throw. Results suggest that an implement lower than 27% could be a useful training tool for athletes that doesn’t impact the velocity or motion of the throw. Studies on discus throwing also support the use of underweight implements without altering kinematics.[55] The use of underweight implements may be a practical tool for decreasing

Musculo-skeletal overwork and injuries due to intense training. It may also be a clinical tool to use in the rehabilitation process of athletes coming back from injuries.[56]

Conclusion

Within the sport of shot putting there are many strategies that can be used to help improve performance. Focusing on building power via strength and conditioning interventions along with using PAP stimuli during competitions are both ways to increase shot putting performance. However, with the lack of accessible PAP stimuli, the use of an overweight or underweight implement may be an option. There are no previous studies evaluating how overweight or underweight implements impact rotational shot-putting performance. With its positive impact on other throwing events, it is a likely tool that can be used in competition.

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CHAPTER THREE

MANIPULATING IMPLEMENT WEIGHT DURING WARM UP TO IMPROVE SHOT PUT PERFORMANCE

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Manipulating Implement Weight During Warm Up to Improve Shot Put Performance

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Abstract

The aim of this study was to investigate the technical, physiological and performance changes in collegiate level shot putters after warming up with differing implement weights. Ten collegiate shot putters participated in this study (6 male, 4 female). Each participant warmed up with either a regulation, overweight, or underweight implement, followed by 6 maximal effort regulation weighted throws. Consistent with previous literature on post-activation potentiation (PAP), those who threw with overweight implements showed significant increases in performance. No changes in critical factor kinematics or ground reaction force measures were impacted by warm up weight. Results of this study conclude that using a heavy implement during warmups is a functional way to improve performance. More research is needed to further understand the mechanisms behind these performance benefits.

Keywords: shot put, post-activation potentiation, kinematics, kinetics, underweight and overweight implements

Word count: 3107

Introduction

The sport of shot putting has been contested since the ancient Greek times and was first introduced into the modern Olympic Games in 1896. Since then, there has been a large body of literature analyzing the biomechanics of the event, with the goal of improving performance. Previous research shows that shot put performance is largely dependent on strength, power, and technique.[1-3] Therefore, much of the existing research on performance enhancement addresses ways to improve these two domains.

From a technical perspective, rotational shot put can be broken down into five phases: (1) double support, (2) first single support, (3) flight, (4) second single support, and (5) release. Each phase being equally important for performance as momentum is generated and transferred to the implement throughout each phase.[4-8] While numerous studies suggest that release velocity is the most important criterion for throw distance,[8,9-11] it is debated how this velocity is generated. Some studies have shown increased release velocities to be a product of high levels of angular momentum along with appropriate timing of the athlete-shot system.[1,2,5] However, other research has highlighted the importance of increasing the separation angle between torso and pelvis during the flight phase, as this results in larger pelvis angular velocities during the delivery.[3,4] Further studies have also highlighted the impacts of knee flexion angles on release velocities. Stating that optimal knee flexion angles during the second single support phase between 105-115 degrees can allow an athlete to generate more power.[12] Thus, leading to a larger amount of force being put into the shot put, ultimately improving performance. These studies all highlight specific factors associated with improved performance; however, few exist identifying training interventions coaches could implement to improve performance or technical factors.

Previous strength and conditioning research is focused on strength and power profiles to improve performance. Tereiz et al.[13] suggests an athletes shot putting performance is largely dependent on levels of absolute muscular strength. This is supported by Judge et al.,[1] who found that throw distance was highly correlated to a 1 repetition maximum clean. This, along with building strength and power in the weight room, reenforces the idea that a shot putter's performance is highly dependent on their power output abilities and can improve performance.

One specific area of increasing popularity within strength and conditioning research is the use of post-activation potentiation (PAP). This phenomenon explains that a muscle's contractile history can enhance its subsequent production of force.[14-16] Previous research shows that movements such as a clean and jerk, bench press or a 20-meter sprint during warmups, yield significant improvements in subsequent shot-put performance.[17-19] However, while useful for training, these exercises are not feasible for most competition environments.

An alternative PAP stimulus more suitable for competition is to manipulate implement weight. Prior studies evaluated the acute effects overweight implement warmups have on weight throwing and over-the-head shot putting performance.[20-22] All studies showed significantly improved throwing distances after using heavy implements during warm-ups. However, the mechanisms behind these positive effects are not fully understood. Current research has yet to identify if increased performance is due to kinematic changes in technique, enhanced by overweight implement warm-ups, or a product of the mechanistic properties PAP. Therefore, this study's purpose was to investigate how warming up with overweight or underweight implements affects both the kinematics and kinetics of the shot-put throw. We hypothesized that the use of overweight and underweight implements during warm-ups will improve shot put distance, increase peak ground reaction force, impulse and rate of force development, along with improving critical factors of technique. Specifically, we expect to see greater pelvic-torso separation angles (second single support–release) and increased pelvic angular momentum (second double support–release).

Materials and Methods

Participants and Protocol

Ten rotational shot putters (4 females, 6 males) participated in this study (Table 1). Data was collected on three separate days with one week between each session. On each day participants completed a self-selected fifteen-minute general warm up, followed by three warm up throws and six maximal effort competition throws. All competition throws were performed using regulation weight shot puts (women: 4.00 kg, men: 7.26 kg). However, implement weight for the warmup throws varied across days. On day one participants used regulation weight implements for warmups, while days two and three were randomized between overweight (men: 8.16 kg, women: 4.53 kg) or underweight (men: 6.35 kg, women: 3.00 kg) conditions. Three minutes of rest time was given between warm up and competition throws along with an additional three minutes of rest between each throw.

Table 1. Participant demographics and performance history.

	Women	Men
Body mass (kg)	89.75 ± 12.50	110.50 ± 6.30
Height (cm)	172.50 ± 2.20	187.32 ± 9.83
Collegiate personal best (meters)	13.15 ± 1.72	14.34 ± 2.10
Clean 1-rep maximum (kg)	88.50 ± 13.40	131.30 ± 25.70

Equipment

Whole body kinematics were recorded using 16-inertial sensors (IMU, MVN Link System, Xsens Technologies B.V, Enschede, Netherlands). Each sensor integrates a tri-axial accelerometer (± 160 m/s^2), gyroscope (± 2000 deg/s), and magnetometer (± 1.9 Gauss), internally sampling at 1000 Hz, and set to export data at 120 Hz. Following manufacturer recommendations (Roetenberg, Luinge, & Slycke, 2009), sensors were placed on the dorsal feet, lateral shanks, lateral thighs, mid-posterior pelvis, middle of the scapular spines, lateral upper arm, lateral forearm, posterior hand, sternum, and posterior head **(Figure 1A).** The biomechanical model was scaled based on anthropometric measures of the participant's height, arm span, shoulder width and height, foot and leg length, hip, knee, and ankle height, and hip width.

Ground reaction forces were recorded using a custom throwing circle containing two force plates (Accupower, dimensions: 1.016 x 0.762 m, manufacturer: AMTI, Waltham MA, USA). Plates were spaced such that during delivery the rear and front foot were on different plates. Force plates were recorded at 120 Hz and the collection of forces and kinematics were synchronized (Figure 1B). Throwing distances were measured using a tape measure to mimic meet like competitions following the World Athletics guidelines.

Figure 1. Anterior and posterior views of the Xsens IMU suite (A) and the force plate instrumented shot put ring (B).

A. **B.**

<u>Data Analysis</u>

The furthest three throws from each condition (baseline (BASE), post-heavy (PH) and post-light (PL)) were used for further data analysis. Events of rear foot touch down (RFTD), front foot touch down (FFTD) and the release (REL) were visually identified in the Xsens MVN Biomech Studio software. Sensor Euler angles and joint angles were exported to MATLAB (MathWorks, Natick MA, USA. Sternum and pelvis sensor orientations were then converted from Euler angles to rotational matrices and the orientation of the pelvis relative to the torso (sternum) was calculated. Pelvis-torso separation at the time of RFTD, rear leg hip flexion at RFTD, rear leg knee flexion at RFTD, and peak pelvis angular velocity around the axial axis between RFTD and REL were then identified.

Ground reaction forces were analyzed and processed in MATLAB. Data was filtered with a low pass Butterworth filter with a 50 Hz cutoff. For both FFTD and RFTD, the forces were analyzed using custom MATLAB code to find impulse, peak force, and peak rate of force development between either FFTD to REL or RFTD to REL.

Statistics

The three best throws within each condition were averaged and used for further analysis. A 2 (sex) x 3 (condition) mixed analysis of variance was used to evaluate differences in dependent variables between conditions, with an alpha of .05 used to indicate statistical significance. To aid in evaluation, effect sizes (Cohen's d) were calculated for all pairwise comparisons and interpreted in the ranges of <0.2 small, 0.4 – 0.6 moderate, > 0.8 large. All statistics were performed using Statistical Package for the Social Sciences (SPSS ver. 29, IBM Corp, Armonk NY, USA).

Results

There were no significant sex-by-condition interactions or main effects of sex for any of the dependent variables. The mean throw distance and participant kinematics are shown in Table **2**. There was a significant main effect of weight on throw distance ($F_{2,16}$ = 4.123, p = .036), with all participants throwing further in the PH condition compared to BASE (p = .002, d = .306; Figure 3. There were no statistically significant differences in any of the kinematic parameters between conditions (Table 2). Ground reaction force variables also showed no statistically significant differences between condition (Table 3).

Table 2. Mean throw distance and kinematics for the baseline (Base), post-heavy (PH), and post-light (PL) conditions. PPAV: peak pelvis angular velocity between rearfoot touch down and release; SH@RFTD: shoulder hip separation at rearfoot touch down; hip@RFTD: rear leg hip flexion at rear foot touch down; Knee@RFTD: rear leg knee flexion at RFTD. * Indicates significantly different thane baseline.

	Women			Men		
	Base	PH	PL	Base	PH	PL
Throw distance (m)	11.41 (± 1.19)	11.89* (± 1.14)	11.82 (± 0.83)	13.15 (± 1.15)	13.54* (± 1.03)	13.21 (± 1.36)
PPAV (°/s)	13.26 (± 1.92)	13.24 (± 1.43)	13.14 (± 0.59)	12.81 (± 2.84	12.66 (± 2.67)	12.50 (± 2.57)
SH@RFTD (°)	40.01 (± 9.31)	40.74 (± 13.19)	30.17 (± 7.73)	29.20 (± 15.42)	29.29 (± 16.52)	26.20 (± 12.44)
Knee@RFTD (°)	44.20 (± 9.43)	43.66 (± 9.83)	48.15 (± 9.39)	43.69 (± 4.75)	40.51 (± 15.08)	41.73 (± 6.91)

Figure 2: Throwing distance vs condition; baseline (BASE), post heavy (PH), post light (PL)

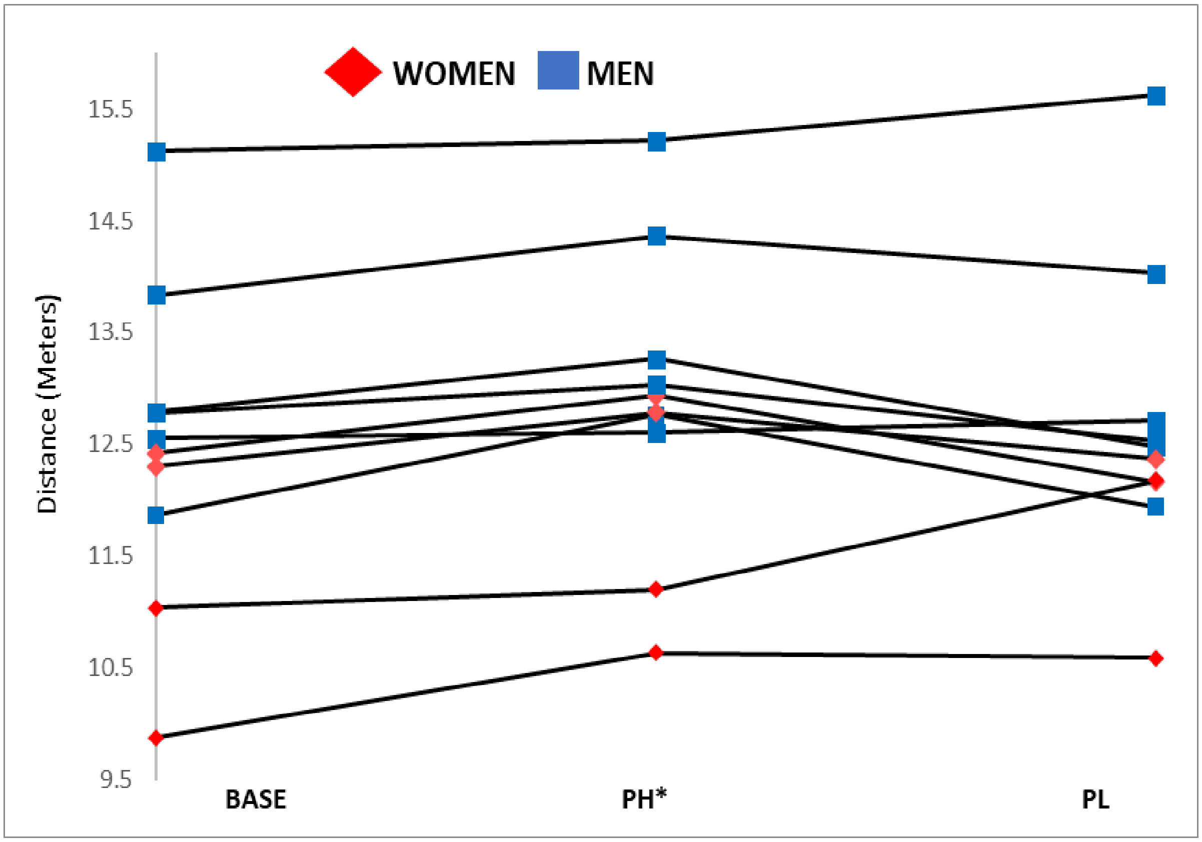

Table 3. Mean ground reaction force metrics for the baseline (Base), post-heavy (PH), and post-light (PL) conditions. PF: peak force on the rear foot (RF) and front foot (FF); Imp: impulse from foot touchdown until release; RFD: peak rate of force development between foot touchdown and release. BW values are combined body and implement weight.

	Women			Men		
	Base	PH	PL	Base	PH	PL
PF-RF (BW*)	1.58 (± 0.16)	1.76 (± 0.42)	1.60 (± 0.11)	1.37 (± 0.13)	1.37 (± 0.11)	1.36 (± 0.15)
PF-FF (BW*)	1.44 (± 0.24)	1.30 (± 0.14)	1.44 (± 0.26)	1.31 (± 0.19)	1.31 (± 0.22)	1.31 (± 0.22)
Imp-RF (BW*s*)	0.41 (± 0.10)	0.42 (± 0.12)	0.39 (± 0.07)	0.31 (± 0.14)	0.43 (± 0.02)	0.34 (± 0.82)
Imp-FF (BW*s*)	0.15 (± 0.06)	0.13 (± 0.04)	0.16 (± 0.03)	0.23 (± 0.15)	0.17 (± 0.04)	0.13 (± 0.05)
RFD-RF ($BW*s^{-1}*$)	41.59 (± 13.33)	44.09 (± 15.54)	45.56 (± 16.54)	32.90 (± 12.61)	27.21 (± 5.01)	28.56 (± 5.18)
RFD-FF ($BW*s^{-1}*$)	38.55 (± 12.40)	37.05 (± 11.04)	37.86 (± 14.97)	29.69 (± 8.74)	33.62 (± 8.27)	30.23 (± 11.27)

Discussion

The purpose of this study was to evaluate the impacts overweight and underweight implement warmups had on performance, kinematics and kinetics of the rotational shot put throw. Results show that every participant in this study improved in the PH condition compared to BASE. Consistent with previous literature[20-22], the main findings of this study support the use of overweight implements during warmups to increase subsequent throw distance using a regulation weight implement. However, contrary to our hypothesis, the increased throw distance was not accompanied by changes in any measured critical factor kinematics or ground reaction force parameters. This suggests other throwing parameters not addressed in this study may have changed and could be responsible for the increase in performance.

Release Parameters

Because the initial variables analyzed in this study did not explain performance increases in the PH condition, additional parameters were evaluated to further investigate potential mechanisms. One set of parameters that may help explain these improvements are release angle, height and velocity of the implement. These release parameters are fundamental in determining the trajectory of a projectile. The release angle of a shot put is heavily dependent on the release velocity, and optimal release angles are often slightly lower than those athletes naturally select.[9-11]

Release parameters were not initially analyzed in this study as the IMU system cannot calculate the mechanics of the implement itself, due to the sensor placement. Thus, we calculated surrogate values for these parameters using hand velocities, angles, distances, and height. MATLAB was used to calculate these measures using the release hand markers and locations. A 2 (sex) x 3 (condition) mixed analysis of variance was used to evaluate differences in release parameters between conditions, with an alpha of .05 used to indicate statistical significance. Women showed a significantly lower release angle in the PL condition compared to BASE ($p=.014$, Table 4) while men showed significant improvements in release velocities in the PH condition compared to BASE ($p=.49$). A heavier implement would be more difficult for an athlete to accelerate vertically as they need to overcome the additional mass. To maintain consistent release velocity, participants may have inadvertently adopted lower release angles with the overweight implement and kept these angles during the competition throws, thus improving their performance. No other release parameters showed significant changes between conditions. While increase in release velocity during the men's PH may have helped contribute to the increase in performance, it is still unclear which mechanisms improved women's performance in the PH condition as release parameters did not change from the BASE condition.

Table 4. Release velocities and angles for both men and women.

	Women	Men
BASE Release Angle (deg)	48.32 ± 1.43	47.10 ± .72
PH Release Angle (deg)	47.47 ± 2.30	46.99 ± 1.99
PL Release Angle (deg)	46.44 ± .81 *	47.37 ± 1.23
BASE Release Velocity (m/s)	9.00 ± 1.03	10.09 ± 1.47
PH Release Velocity (m/s)	9.64 ± 1.02	11.10 ± 1.40*
PL Release Velocity (m/s)	10.31 ± .88	9.98 ± 1.32

Future research using different methodologies to determine if overweight implements influence throw kinematics and release parameters is still needed. As implement release parameters are strongly associated with upper extremity kinematics,[10.13.24] it is possible there were beneficial changes in these values as well. The IMU system used in this study cannot calculate the true release parameter values, however, the surrogate measures used were consistent between participants.

Post Activation Potentiation

Alternatively, the improvements in throw distance might be due to the mechanistic properties of PAP. PAP results from the combined effects of increased phosphorylation of myosin and increased motor unit recruitment rates.[18,23] The increased phosphorylation of myosin impacts the muscles reactivity to calcium thus increasing its force production. Similarly, the increased motor unit recruitment rates are caused from synaptic excitation inside the spinal cord. This excitation in the spinal cord then leads to an increase in post-synaptic potentials and an increase in force production. Terzis et al.[24] demonstrated that earlier onset of triceps brachii activation was associated with better shot-put performance. It is possible the PAP stimulus provided by using the overweight implements resulted in greater motor unit recruitment speeds in the triceps brachii or other muscles, thereby, allowing them to generate forces faster or at a more optimal time in the throw. Future studies using EMG on both upper and lower extremities are required to investigate this hypothesis.

Limitations & Further Directions

Only ten rotational shot putters participated in this study; three of whom only had one year of experience with rotational technique. There was a large effect size, (Cohen's d: 1.38) for throw distance in the post light condition as it compared to baseline. With this large effect size for the light condition, we can conclude that this study may be underpowered. More research including a larger number of participants may shed light on the mechanistic properties associated with these improvements in performance.

The relative magnitude of the implement weights used could also have been a limiting factor in the PL condition of this study. The PH for men and women was 112.5% and 113.6% of the competition weight; respectively. Whereas in the PL condition women threw a 75% implement while the men threw an implement which was 87.5% of regulation weight. However, the reasoning for using these specific percentages was due to the commonality and commercial availability of implements. A further study using custom shotput weights to evaluate consistent percentages and more levels of underweight or overweight conditions may be beneficial.

The strength profiles of individual athletes may also be a factor in determining which stimuli best improves performance. The two men with the heaviest clean maximum were also the only two men who performed worse in the PL condition compared to BASE. However, on the women's side, the subject with the strongest clean maximum showed the most improvement after the PL condition. Men with a higher strength profile may be less impacted on the muscular level by a "lower level" overweight implement compared to a "higher level" overweight implement, due to motor recruitment properties. Whereas women with higher strength levels may be impacted more by lighter implements due to the increase of motor recruitment in fast twitch muscle fibers. More research on PAP impacts on shot putting performance that considers muscle fiber type and a greater number of strength measures is needed.

Future Implementations and Coaching Interventions

With the improvement in performance during the PH condition, we can conclude that the use of this strategy during competition is beneficial. The lack of significant findings within the kinematics and kinetics between conditions does not explain the acute performance benefits seen in the PH condition. However, it also means there were no negative changes in kinematics or kinetics between conditions. Therefore, the use of overweight and underweight implements may also be useful when periodizing training. Prior literature supports the use of high volume and low intensity during the preparatory period and a switch to high intensity and low volume during the competition period.[25-28] The use of overweight implements to increase volume and underweight implements to increase intensity may be a possible mode of training.

Conclusion

The use of an overweight implement during warmups improves rotational shot-put performance without changing the critical factor kinematics or ground reaction forces of the throw. Since competition rules allow athletes to weigh in heavier implements for warmups, the use of this strategy could be one way for athletes or coaches to improve acute performance. It also opens the possibility of overweight and underweight implements to be a practical tool for training. More research evaluating just how impactful overweight and underweight implement is needed.

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CHAPTER FIVE

CONCLUSIONS AND FUTURE DIRECTION

The shot put is a commonly contested track and field event with a rich history in the Olympic Games dating back to 1896. Since then, there have been many advancements in applied sports science and biomechanics to help improve performance. These improvements have been largely due to either improvements in technique or strength and conditioning.

One area of increasing research in the shot put regards the phenomenon of Post Activation Potentiation (PAP), the idea that a muscles contractile history can enhance its subsequent force production.[1-3] Research on the PAP and shot-putting show that by using stimuli such as a countermovement jump, bench press, clean and jerk, or a 20-meter sprint athletes can significantly enhance performance.[4-6] Further research evaluating PAP stimuli via overweight implements also show an improvement in performance in both the weight throw and overhead back shot putting.[7-9] However no studies have been done evaluate overweight or underweight implements impact on the rotational shot put throw.

In this study the goal was to evaluate the impact of overweight and underweight warm up throws on both the performance, kinematics and kinetics of the rotational shot put throw. With the goal of further uncovering the mechanisms behind this phenomenon of PAP. Results of this study show a significantly improved performance after warming up with an overweight implement compared to baseline. However, no kinematic or kinetic variables showed any changed between conditions. Due to this lack of evidence to explain these performance enhancements further release parameters were evaluated.

Results showed that women had a significantly lower release angle after the underweight condition and men showed a significantly higher release velocity in the overweight condition. These results still leave gaps when trying to understand the reason for performance enhancements. For the men it is likely that the overweight implement helped to prime the muscle thus leading to larger forces and ultimately higher release velocities leading to further distances. However, women didn't show any significant improvements in any kinematic or kinetic variables when looking at the overweight condition. More research including a larger number of participants is needed. Further evaluation into upper body kinematics along with release parameters is also important for further understanding the performance benefits associated with overweight and underweight implements.

However, the lack of kinematic and kinetic changes between conditions may be helpful when looking at ways to further improve performance. The results of this study show an acute improvement in performance using overweight implements in warm ups, however off weighted implements may also hold value when used for training purposes. Periodization of training research has shown that training at high volume during the off season is important to improving performance.[10,11] The use of overweight implements during off season training may be a theoretical tool to help improve performance. Likewise training low volume but high intensity during competition periods is also important when periodizing training. The use of underweight implements may be a useful tool when peaking athletes for competition. More research on these theoretical training interventions is needed.

Overall, this study is important for helping to acutely improve shot putting performance. The use of overweight implements in warmups significantly improves shot putting performance.

Competition rules allow athletes to weigh in heavy implements therefore, the use of this strategy is a useful tool for athletes and coaches to use.

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