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Original Research

Effects of medicine ball mass on the intensity of 90°/90° plyometric throwing exercise

Bryan L. Riemann*, Nick Hipko, Wayne Johnson, Thomas Murphy, George J. Davies

Biodynamics and Human Performance Center, Georgia Southern University-Armstrong Campus, 11935 Abercorn Street, Savannah, GA, 31419, USA

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ABSTRACT

Objectives: To quantify the effects of medicine ball mass (1 kg, 1.5 kg, 2 kg) on the intensity of 90°/90° plyometric throwing exercise.
Study design: Controlled laboratory study.
Setting: Biomechanics laboratory.
Participants: Fifteen physically active collegiate aged men.
Main outcome measures: Kinematics of the upper extremity were collected during completion of eight to ten repetitions of 90°/90° plyometric throwing exercise with three different mass medicine balls. Four parameters, medicine ball release and contact momentum, time-to-rebound, and contact time, were computed for each selected repetition and used for statistical analysis.
Results: Ball mass did not significantly influence time-to-rebound ($P = .718$) and had a small (less than 0.05s) effect on ball contact time ($P = .039$). Ball release momentum was significantly greater ($P < .001$, 67–123% greater) than ball contact momentum. Medicine ball mass significantly increased both ball release (34–35%) and ball contact (45–67%) momentum however the effect was significantly greater for ball release momentum ($P = .005$).
Conclusions: These results document the effects of increasing medicine ball mass during 90°/90° plyometric throwing exercise and provide evidence for designing upper extremity plyometric training programs. Based on ball contact momentum being less than ball release momentum, as well as ball mass having greater influence on ball release velocity, we suggest that 90°/90° plyometric throwing exercise is a safe exercise.

1. Introduction

Upper extremity injuries are common among athletes (Goodman et al., 2018; Hootman, Dick, & Agel, 2007; Lin, Wong, & Kazam, 2018), and without proper intervention, can lead to strength, power and neuromuscular control deficits (Edouard et al., 2011; Stickley, Hetzler, Freemyer, & Kimura, 2008) thereby possibly predisposing the individual for further pathology (Forthomme et al., 2018). During the terminal phases of a rehabilitation program, the focus shifts to restoration of functional abilities, particularly the movement patterns, velocities and force demands. Many sport-related activities require the upper extremity muscle-tendon units to absorb and produce forces in short periods of time making improvement in timely force absorption and production a paramount focus of performance enhancement programs and rehabilitation programs. It is for these reasons that upper extremity plyometric exercise becomes a mode of exercise used by both clinicians and strength and conditioning specialists (Davies, Riemann, & Manske, 2015).

Compared to lower extremity, fewer investigations have examined upper extremity strength and power adaptations to plyometric exercise (Carter, Kaminski, Douex, Knight, & Richards, 2007; Schulte-Edelmann, Davies, Kernozek, & Gerberding, 2005; Swanik et al., 2016). Singla et al. (Singla, Hussain, & Moiz, 2017) recently concluded after conducting a systematic review of eleven randomized controlled trials that upper extremity plyometric exercise has a large effect on improving ball throwing velocity, moderate effect on improving ball throwing distance but only a negligible effect on improving upper extremity muscle strength. In contrast to the small upper extremity strength improvements, large lower extremity improvements have been more consistently

* Corresponding author.
E-mail address: briemann@georgiasouthern.edu (B.L. Riemann).
@BryanRiemann (B.L. Riemann)

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demonstrated (de Villarreal, Kellis, Kraemer, & Izquierdo, 2009). Similar to designing any exercise program, successfully promoting adaptations requires an understanding of the program variables such as intensity, volume, frequency, progression and recovery. In contrast to the plethora of evidence documenting these program variables for lower extremity plyometric exercises, quantification and evidence to support decisions regarding the above program variables for upper extremity plyometric exercises is sparse. Without objective data to guide program design, practitioners and researchers choose program design variables based upon anecdotal evidence (Ebben, Blackard, & Jensen, 1999) and personal experience. It is plausible that the upper extremity plyometric programs reviewed by Singla et al. were deficient in one or more program design elements, and thus by extension, might help to explain the discrepancy in strength improvements between lower and upper extremity plyometric exercise programs. If there is inadequate overload and progression to the rehabilitation or training programs, then under-dosing the volume loading is ineffective in producting gains with plyometric exercises.

The upper extremity plyometric exercises that have been studied the most are plyometric pushups (Dhahbi et al., 2017; Garcia-Masso et al., 2011; Hinshaw, Stephenson, Sha, & Dai, 2017; Koch, Riemann, & Davies, 2012; Moore, Tankovich, Riemann, & Davies, 2012). Despite their widespread clinical utilization, less research (Ebben et al., 1999; Ellenbecker, Sueyoshi, & Bailie, 2015; Maenhout, Benzoor, Werin, & Cools, 2016) has quantified the intensity of the numerous open kinematic chain upper extremity plyometric exercises conducted with medicine balls. The plyometric exercise that may best replicate the functional activity involved in major overhead sports such as baseball, softball, tennis, and volleyball is the 90°/90° plyometric throwing exercise (Davies et al., 2015). This exercise involves throwing a small medicine ball from a position of 90° of shoulder abduction/90° of elbow flexion at a slanted trampoline and then catching the rebound of the ball by allowing the shoulder to rotate into external rotation. Various mass medicine balls can be used to progressively overload the shoulder musculature; however, no research currently exists regarding the intensity of 90°/90° plyometric throwing exercise nor the effects of increasing the mass of the medicine ball on exercise intensity. In addition to intensity, the time to rebound, traditionally referred to as amortization time, as well as the contact time are important components to plyometric exercise and largely reflects efficiency and coordination of the movement (Davies et al., 2015). Thus, the current study sought to quantify the effects of medicine ball mass (1 kg, 1.5 kg, 2 kg) on the intensity of 90°/90° plyometric throwing exercise as reflected by medicine ball release and contact momentum, time-to-rebound and contact time in physically active collegiate men. We hypothesized that as the medicine ball mass increased, there would be an increase in ball contact time and time-to-rebound, as well as ball contact and release momentum, however the effect would be greater for ball contact than ball release momentum. Ball contact momentum reflects the initial loading imposed on the upper extremity at the beginning of the eccentric phase while ball release momentum provides an summary indication of the concentric phase effort.

2. Methods

2.1. Participants

Using data from a preliminary study (Moore, 2012) investigating 90°/90° plyometric throwing exercise, it was estimated that 12 participants would be needed ($\alpha = 0.05$, $\beta = 0.20$) to attain statistical significance with a clinically meaningful ball mass effect size (η (Davies et al., 2015)$_p = .4$). To account for possible magnitude and variability differences between the preliminary and the current study samples, fifteen volunteer men (23.8 ± 3.3 years, 86.0 ± 11.5 kg, 1.81 ± 0.05 m) completed all study procedures. Participants provided a list of typical weekly physical activities (types and length). All participants were physically active, defined as participating in some form of physical exercise at least three times per week for a minimum of 30 min per session, as per the American College of Sports Medicine guidelines (Garber et al., 2011). In addition, participants had to demonstrate proficiency in correctly performing the 90°/90° plyometric throwing exercise. Potential participants were screened for precluding health-related factors through completion of a medical questionnaire. Exclusion criteria included participants with cervical spine, shoulder, elbow, or wrist injuries within the past six months or who regularly participated in a sport that emphasized use of one arm over the other (i.e., baseball, tennis, softball, volleyball). In addition, none of the subjects had surgery of the shoulder or elbow in the last year. The study received Institutional Review Board approval and prior to any study procedures, subjects reviewed and signed an Institutional Review Board approved consent form.

2.2. Experimental design

Prior to completing a single 45-min data collection session, all subjects initially completed a screening/familiarization session. During the session, participants completed several trials using 11.4 cm diameter 1 kg, 1.5 kg, and 2 kg medicine balls (TheraBand Soft Weights, TheraBand, Akron, OH) to ensure they could correctly perform the 90°/90° plyometric throwing exercise using their dominant limb. During the second study session, scheduled 72–96 h following the familiarization session, participants completed the 90°/90° plyometric throwing exercise while kinematic data of the upper extremity was collected. To assist in controlling for any potential multiple exposure and fatigue effects, participants were randomly assigned a ball mass order.

2.3. 90°/90° plyometric throwing exercise procedures

Prior to completing the plyometric throwing exercise during either the familiarization or data collection session, participants completed a warm up exercise bout. First, participants completed a 5-min bout on an Upper Body Ergometer (Cybex Aerobic Ergometer, Boston, MA), cycling between 30 s of forward pedaling and 30 s of reverse pedaling at a rate of ninety rpm with a self-selected resistance that equated to a ten to twelve rating of perceived exertion on the Borg scale. Next, participants were guided through 30 s each of forward shoulder circles, reverse shoulder circles, and arm swings in the shoulder horizontal abduction/adduction plane.

Following the warm-up for the familiarization session, subjects were given an overview of plyometrics and specifically, the 90°/90° plyometric throwing exercise. Emphasis was placed on maintaining the 90°/90° position during the throw; throwing with maximal effort; allowing the ball to stretch the shoulder musculature into external rotation just prior to the subsequent throw and minimizing the time between eccentric and concentric action of the shoulder internal rotators (Fig. 1). This technique was explained and demonstrated for each participant. Before the participants began practicing their technique, they were fitted with a basic cotton glove on their dominant hand that would simulate the glove used for data collection. Each subject then threw each of the three weighted balls, the order of which was randomized for each participant, between 10 and 20 times each, practicing proper form and progressively increasing throwing velocity. After instruction and practice, participants that could complete 8–10 consecutive repetitions while maintaining proper technique were scheduled for

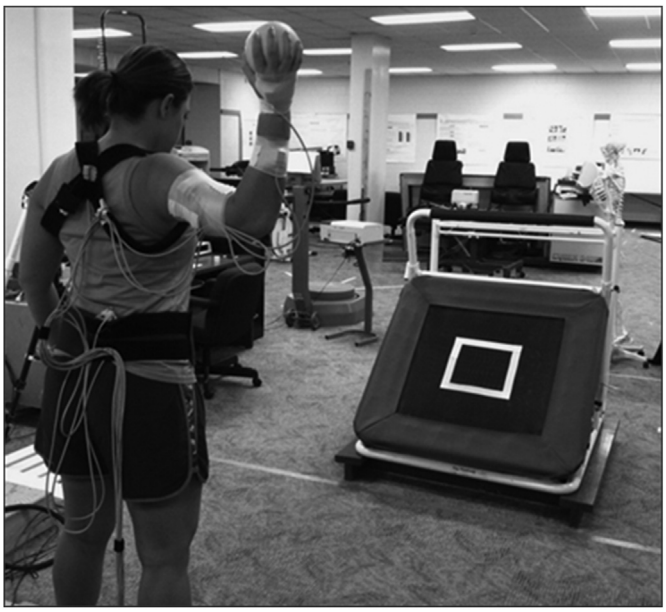

Fig. 1. During the plyometric throwing exercise, participants were required to maintain the shoulder at 90° abduction and 90° elbow flexion.

a subsequent data collection session.

For the data collection session, following completion of the warm-up, participants were instrumented with a pressure sensitive glove and electromagnetic sensors on their dominant limb. Participants then completed 10 to 12 plyometric throws using their dominant limb using each of the three mass medicine balls while data collection occurred. The order of the ball masses was randomized between participants with 1-min rest given between each ball mass. Prior to data collection for each ball mass, participants were allowed 8 to 10 practice throws to adjust to the different ball masses.

2.4. Data collection and reduction

Participants wore a custom designed pressure sensitive glove on their dominant hand to indicate medicine ball contact and release (Johnson et al., 2015). Integrated into the gloves were six pressure sensors located at the distal end of the four fingers and two across the palmar aspects of the metacarpophalangeal joints. The sensors consisted of a neoprene frame with two layers of copper fabric, separated with two layers of Velostat™ to form an electrical switch. The six sensors were wired in parallel with each other. The parallel combination of the sensors was in series with a 4.7 kOhm pull-down resistor and a 4.5 V battery pack. Pressure applied to single or multiple sensors produced a signal above 4 V across the pull-down resistor. The voltage across the pull-down resistor was 0 V when pressure was removed from all sensors. The voltage measured across the pull-down resistor thus could be used to determine ball contact and release times.

Additionally, an extended range electromagnetic tracking system (MotionStar, Ascension, Inc., Shelburne, Vermont) captured kinematic data of the torso and dominant limb hand, lower, and upper arms. Electromagnetic receivers were fixed to the dorsal aspect of the hand, lateral lower and upper arm, and seventh cervical vertebrae spinous process using a combination of double sided and surgical tapes. Creation of local axes for each body segment as well as the hand relative to the hand sensor were established by digitizing the proximal-superior and distal-inferior hand and torso segment ends using a calibrated stylus. Synchronization and collection of signals from the pressure sensitive glove (1000 Hz) and electromagnetic sensors (140 Hz) was conducted using The Motion Monitor (Innovative Sports Training, Inc., Chicago, IL) data collection platform.

Kinematic data reduction was conducted offline using MatLab (The Mathworks, Inc., Natick, MA) based scripts. First, all kinematic data were low-pass filtered with a zero-phase lag Butterworth filter (10 Hz cutoff). Five repetitions were chosen for data reduction based upon selection of the first five repetitions with the cleanest glove signals (clear ball contact/release signals). Using the synchronized signals from the gloves indicating ball contact and release, a set of four variables were computed from the hand with respect to the global axes system. Using the assumption that the hand and ball were moving together at the instant of ball release and contact, ball release and contact velocities were computed as the average three-dimensional hand velocity of a 0.1 s window around the ball release and contact signals provided by the glove. To establish the intensities of the 90°/90° plyometric throwing exercise, ball release and contact velocities were multiplied by the medicine ball masses to establish ball release and contact momentum. Ball contact time was computed as the time interval between ball contact and ball release. Time-to-rebound was computed as the time interval between ball contact and when the hand transitioned from moving posteriorly to anteriorly. The average of each variable across the five repetitions was computed and used for statistical analysis.

2.5. Statistical analysis

Exploratory analysis for normality was conducted using visual inspection of the boxplots followed by Shapiro-Wilk tests. Separate one-way repeated analysis of variance (RMANOVA) were conducted on the ball contact time and time-to-rebound variables to evaluate the effects of ball mass, followed by Bonferroni adjusted pairwise post hoc comparisons as necessary. A phase (ball release, ball contact) by ball mass (1.0 kg, 1.5 kg, 2.0 kg) was conducted on the ball momentum variables. Post hoc analysis of a significant interaction was conducted using trend analysis to identify the overall effects of ball mass on ball contact and release momentum followed by simple main effect post hoc comparisons with Bonferroni adjustments. For all post hoc tests, Hedges's g effect sizes, adjusted for small samples (Hedges, 1982), were computed. Significance for all inferential statistics was set *a priori* to $\alpha \leq 05$. All statistical analyses were conducted with SPSS 25.0 statistical software (SPSS, Inc, Chicago, Il).

3. Results

During data reduction, it was realized that the glove signals for two participants were atypical for one of the ball masses (1 kg for one participant, 2 kg for second participant), which was likely caused by the battery becoming loose. Thus, the statistical analysis was conducted on the 13 participants with complete data. Exploratory analysis revealed slight normality issues (positive skewness) for ball contact times (all ball masses), ball contact momentum (1 kg and 2 kg) and ball release velocity (1.5 kg). Natural log transformations resolved the normality departures. Identical statistical RMANOVA results were obtained with both the original scale and natural logarithm transformed data. Coupled with the robustness of the RMANOVA to slight departures in normality (Gamst, Meyers, & Guarino, 2008), the results using the original scale are reported.

Although the omnibus test for the effect of ball mass on ball contact time was statistically significant ($F_{2,24} = 3.7$, $P = .039$, η (Davies et al., 2015)$_p = .624$), the differences were very small with

none of the adjusted pairwise comparison P values statistically significant (Table 1). The times to rebound were statistically equal ($F_{2,24} = 0.34$, $P = .718$, η (Davies et al., 2015)$_p = .027$) between the 1.0 kg (0.21 ± 0.07s), 1.5 kg (0.20 ± 0.08s), and 2.0 kg (0.21 ± 0.07s) ball masses.

Ball momentum increased as the medicine ball mass increased (Fig. 2), however the effect was not the same between the phases ($F_{2,24} = 4.88$, $P = .017$, η (Davies et al., 2015)$_p = .289$). Across the three ball masses, ball momentum increased in a linear manner (ball release: $P < .001$, η (Davies et al., 2015) $_p = .932$; ball contact: $P < .001$, η (Davies et al., 2015) $_p = .900$), with the linear trend for ball release statistically greater than ball contact ($P = .005$, $g = 0.75$). Neither the quadratic trend for ball release ($P = .219$, η (Davies et al., 2015) $_p = .123$) nor ball contact ($P = .549$, η (Davies et al., 2015) $_p = .031$) were statistically significant. The pairwise comparisons between ball masses within each phase revealed the 1.5 kg medicine ball to result in a 33% ($P = .003$, $g = 1.02$) and 67% ($P < .001$, $g = 2.31$) greater momentum compared to the 1.0 kg medicine ball and the 2.0 kg medicine ball to result in a 35% ($P < .001$, $g = 1.22$) and 45.1% ($P < .001$, $g = 1.49$) greater momentum compared to the 1.5 kg medicine ball for ball release and contact, respectively. The results of the post hoc comparisons between phases revealed ball release momentum to be greater than ball contact momentum across the 1.0 kg ($P < .001$, $g = 3.31$), 1.5 kg ($P < .001$, $g = 1.87$), and 2.0 kg ($P < .001$, $g = 2.21$) balls.

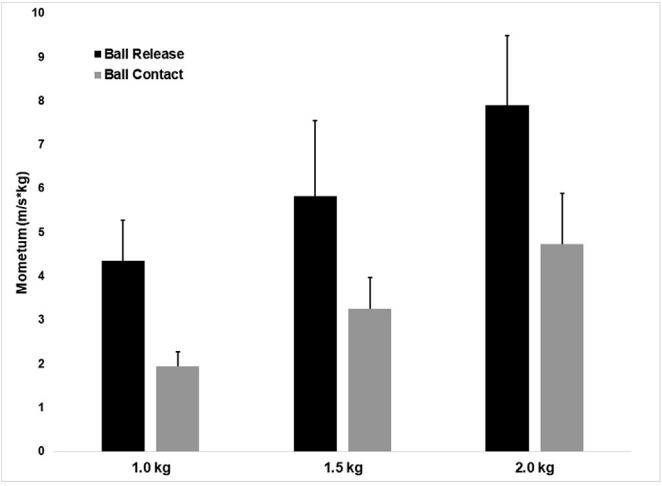

Fig. 2. Ball release (black bars) and contact (gray bars) momentum. While momentum increased significantly linearly within each phase, the increase was significantly greater for ball release momentum. Error bars are standard deviations.

4. Discussion

The current study sought to quantify the effects of medicine ball mass (1 kg, 1.5 kg, 2 kg) on the intensity of 90°/90° plyometric throwing exercise as reflected by medicine ball release and contact momentum, time to rebound, and contact time in physically active collegiate men. We hypothesized that as the medicine ball mass increased, there would be an increase in ball contact time and time-to-rebound, as well as ball contact and release momentum, however the effect would be greater for ball contact than ball release momentum. In contrast to our hypothesis, neither ball contact time nor time-to-rebound changed with ball mass. Most remarkable was the quantification that ball release momentum was substantially greater than ball contact momentum, and in contrast to our hypothesis, ball mass influenced ball release momentum to a larger extent than ball contact momentum. Ball release momentum is under the direct control of the individual (i.e., volitional effort), because this is the concentric power production performance phase of the plyometric action. In contrast, contending with ball contact momentum, similar to ground contact momentum during lower extremity plyometrics such as drop jumps, is beyond the control of the individual. However, this is where the volume dosage loading for the 90/90 plyometrics would be important, just as increasing the height of a lower extremity plyometric depth jump box height increases the body momentum at ground contact and therefore the ground reaction force magnitude. Based on the documentation of ball contact momentum being less than ball release momentum, coupled with the ball mass having a greater influence on ball release velocity, we suggest that 90°/90° plyometric throwing exercise is a safe exercise.

Our methodology relied on the assumption that the hand and medicine ball were moving in unison at the instant of ball release and contact. Additionally, our approach of averaging the three-dimensional hand velocities around a window of ball release and contact likely resulted in a conservative estimate of true ball velocity. However, because the same method was used for all three ball masses, the relative differences in ball release and contact velocities revealed between the ball masses would remain identical if a different window size around ball contact/release had been used. Furthermore, we considered the three-dimensional velocity around ball contact and release. The largest component of the three-dimensional vector was the anterior-posterior component followed by the vertical component. The exact magnitude of the three-dimensional vector components coupled with position of the hand relative to the trunk dictates the exact loads across the joints of the upper extremity. As this was the first investigation of assessing the intensity of 90°/90° plyometric throwing exercise, we choose to consider the composite vector to determine the overall effect of ball mass on exercise intensity. Future research is needed to consider the loading across each of the joints comprising the upper extremity to fully understand the demands imposed by the 90°/90° plyometric throwing exercise.

The ideal plyometric training load causes sufficient loading, particularly eccentric, to promote positive adaptations without inducing excessive exaggeration of the time to rebound and movement range of motion (Ebben et al., 1999). Interestingly, ball mass did not influence time to rebound and had only a slight effect on contact time. We attribute these results to limiting the study

Table 1
Descriptive statistics and post hoc results for ball contact times (s). Effect sizes are given as adjusted Hedges's *g*.

Ball Mass	Mean ± SD	Bonferroni Adjusted Comparison Results					
		1 kg ball			1.5 kg ball		
		P	Effect Size	95% CI_{diff}	*P*	Effect Size	95% CI_{diff}
1 kg	.45 ± .09						
1.5 kg	.44 ± .11	1.00	.04	-.041–.049			
2 kg	.48 ± .11	.119	.32	-.071–.007	.060	.31	-.074–.001

SD: standard deviation; 95% CI_{diff}: 95% confidence interval of the difference.

participation to healthy men who possessed enough upper extremity strength to overcome the increased intensity afforded by heavier medicine balls without altering the time to reverse the momentum of the medicine ball or to perform the entire movement. We speculate that if we had used weaker individuals, such as patients recovering from upper extremity injury or surgery, differences in time-to-rebound and contact time would have occurred as ball mass increased. Because the increase in ball mass did not increase time-to-rebound or ball contact time, practitioners may want to select a heavier mass medicine ball to increase the total power performance when working with healthy individuals.

The intensity of the forces during the different phases of the plyometric movement patterns need to be established to establish the optimum volume dosage for training. Because of the vulnerable position of the shoulder in the 90/90 position, it is also important not to create excessive loading because of the possibility of iatrogenically creating an overuse tendonitis/synovitis to the rotator cuff muscles. Again, the most remarkable and clinically relevant finding in the current study was difference between the ball release and contact momentum. Ball release momentum represents the voluntary cumulative muscular effort of the concentric phase of the exercise, while ball contact momentum represents the initial load imposed onto the upper extremity during the eccentric phase of the exercise. The decrease of ball momentum between ball release and contact momentum is attributed to the trampoline absorbing some of the kinetic energy of the ball. Clinically, this finding provides evidence that 90°/90° plyometric throwing exercise is a safe exercise for patients as a patient can volitionally throw the medicine ball as hard as possible with the understanding that the loading part of the exercise will involve contending with less intensity during the eccentric muscle action.

Furthermore, although the percent increases for ball contact momentum were greater than ball release momentum, the absolute values of the increases were significantly greater for ball release momentum compared ball contact momentum as evidenced by the post hoc linear trend comparisons. While this result might also further support the safety premise associated with progressing the intensity of 90°/90° plyometric throwing exercise for patients, it might help partially explain the lack of evidence supporting upper extremity strength adaptations in response to 90°/90° plyometric throwing exercise (Singla, Hussain, & Moiz, 2017). In their study of the intensity of medicine ball drop exercise, Ebben et al. (Ebben et al., 1999), based on the results of previous investigations (Lyttle, Wilson, & Ostrowski, 1996; Wilson et al., 1993, 1996), placed an emphasis on adjusting medicine ball mass and height to achieve an impact load equal to 30% of a one repetition maximum to ensure sufficient eccentric loading for promoting training adaptations. Computing medicine ball momentum for the lowest drop height (0.93 m) and lightest medicine ball mass (2.73 kg) described by Ebben et al. yields an impact momentum of 11.5 kg*m/s. The greatest ball contact momentum in the current study was 4.7 kg*m/s with the 2.0 kg medicine ball. Although this analysis provides an intensity comparison between medicine ball drop and 90°/90° plyometric throwing exercise, the two exercises utilize different movements and muscle activation patterns. While medicine ball drop exercise involves a bench press-like movement pattern, the 90°/90° plyometric throwing exercise largely utilizes glenohumeral rotation and horizontal abduction/adduction. Combining the earlier suggested future research determining the loads across each of the upper extremity joints during 90°/90° plyometric throwing exercise, coupled with one repetition maximum testing of the relevant movement and muscle patterns, is needed to determine if the intensity provided by the medicine balls in the current study attain the eccentric loading threshold needed to promote strength and power adaptations.

Additionally, because ball release momentum, and therefore ball contact, is dictated voluntarily by the exerciser, weaker individuals might not initially perform the 90°/90° plyometric throwing exercise with the same vigor as our participants. Because this was the first investigation considering the intensity of 90°/90° plyometric throwing exercise, we purposefully chose to consider individuals who could clearly handle the range of demands imposed by the range of medicine ball masses and the intensity of the plyometric movements. The results of this study provide a foundation for future research to study 90°/90° plyometric throwing exercise in patients recovering from upper extremity pathology.

In conclusion, these results document the effects of increasing medicine ball mass during 90°/90° plyometric throwing exercise and provide evidence for designing upper extremity plyometric training programs. Ball release momentum is the result of voluntary concentric power production. In contrast, ball contact momentum is not under the direct control of the individual. Based on ball contact momentum being less than ball release momentum, as well as ball mass having greater influence on ball release velocity, we suggest that 90°/90° plyometric throwing exercise is a safe exercise.

Funding

None declared.

Ethical approval

This study received institutional review board approval and all participants signed informed consent documents.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.10.002.

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