Upper Limb Kinematics During Medicine Ball Throws Performed in Different Positions

Jirapat Tangkiattrong* Dr.Weerawat Limroongreungrat* Parunchaya Jamkrajang* Dr.Chris Mawhinney*
Dr.Taspol Keerasomboon*[1]

ABSTRACT

Many studies have examined lower extremity (LE) kinematics during plyometric exercise but there remains a limited number of studies investigating kinematic changes during Upper extremities (UE) plyometric exercises. Medicine balls are commonly used for UE plyometric exercise training and can provide an indirect measure of upper-body power. The aim of this study was: 1) to compare the UE kinematics, ball power, and ball velocities between three medicine ball throw positions, and 2) to determine UE kinematic variability among these medicine ball throwing tests. Ten male basketball collegiate players volunteered in this study. Four inertial measurement unit (IMU) sensors at 200 Hz. Participants were asked to perform five trials of medicine ball weighing 5 kg throws from chest level including 1) seated chest throw (SIT), 2) kneeling chest throw (KN), and 3) standing chest throw (ST). Peak ball velocity was significantly different between conditions with a higher peak ball velocity in the ST position compared with the SIT and KN positions. The shoulder ROM in the SIT position was significantly greater compared with the KN position. For UE movement variability showed consistency for the shoulder and elbow ROM for kinematic variables across all conditions. The ST position showed a greater peak ball velocity compared with the KN and SIT positions. Paradoxically, shoulder ROM was greater in the SIT position. There appeared acceptable variability in kinematic variables across the different throwing positions, this suggests that reliable measures of medicine ball plyometric performance may be obtained using the ballistic medicine ball.

Keywords: Accelerometer; Chest throw; Inertial measurement unit; Kinematics; Plyometric

---

[1] *Corresponding author: Dr.Taspol Keerasomboon, Ph.D, 999 Phuttamonthon 4 Rd, Salaya, Phuttamonthon, Nakhonpathom, E-mail:taspol.kee@mahidol.ac.th*

**College of Sports Science and Technology, Mahidol University, Thailand*

Introduction

Plyometric exercise is characterized by the stretch-shortening cycle (SSC); a fast eccentric loading to facilitate subsequent concentric force(1-8). The stretch shortening cycle is a mechanism of the human muscle–tendon complex (MTC) for improving both the performance and economy of motion. It primarily involves the mechanical properties of MTC and utilizes an elastic energy storage–recoil process and muscular tension transmission(7) Indeed, the effectiveness of lower extremity (LE) plyometric training programs are commonly assessed via rate of force development (RFD) using force platforms during jump performance tests, such as countermovement jumps (CMJ) or drop jumps (DJ) while many studies have examined LE kinematics during upper extremity (UE) plyometric exercise, in contrast, there still remains a limited number of studies which have documented kinematic changes during UE plyometric exercises. Moore et al. (2012) investigated UE kinematics and ground reaction force (GRF) during 4 push-up positions (box drop push-ups from various heights, and clap push-ups) using two force plates, however, power was not directly measured. Despite the study being considered a seminal UE plyometric investigation, push-up tests performed on a force platform may not be a suitable field test(9).

Medicine balls are commonly used for UE plyometric exercise training and can provide an indirect measure of upper-body power(10). Recent technological advancements have enabled embedded accelerometers to be inserted inside medicine balls to provide an estimate of UE power. These types of medicine balls have been validated in professional rugby union players(11) and resistance males and females using the supine and standing chest throw(12), respectively. However, there are several variations of medicine ball throw tests that can be performed in the field in other positions, i.e., seated, standing and kneeling overhead medicine ball throwing positions. To our knowledge, no previous studies have attempted to examine differences in UE kinematics and power among different variations of medicine ball throwing tests. Additionally, repeatability of these tests have yet to be explored using a medicine ball with an inserted accelerometer using the variability of UE motion method, which has recently been adopted for biomechanical assessments across several sporting activities(13).

Accordingly, the purpose of this study was to: 1) to compare the UE kinematics, ball power and ball velocities between three medicine ball throw positions, and 2) to determine UE kinematic variability among these medicine ball throwing tests. We hypothesized that there would be differences in UE kinematics and variability between the different medicine ball throw tests.

Materials and methods

Study design and participants

Ten male basketball collegiate players (2 point guards, 2 shooting guards, 2 small forward, 2 power forward, 2 centers) participated in this randomized control trials research. (mean±SD: age, 21.1±2.3 years; weight, 64.9±6.3 kg, and height 171.6±8.4 cm) volunteered to take part in this study. The sample size was calculated using G*Power 3.1.9.4. The effect size for sample size calculation was based upon (Cronin and colleagues (2004) using upper-body strength and power assessment in women during a chest pass (14). The estimated total sample size was 8 participants and 20% dropout rate has been added, Therefore, in total sample size of 10 participants were recruited. A significance level was set at $p< 0.05$. Participants get capable of lifting one-repetition maximum bench press equal to or more than body weight. All participants trained for at least 3 days per week and on average for 2 hours per session. Participants were excluded if they had a history of upper extremity injury or surgery within the past 12 months. Prior to the study, all participants provided their informed consent to participate and the study procedures were a priori approved by University Institution Review Board (MU-CIRB 2020/270.1409).

Testing

Prior to experimental testing, participants were asked to perform the warm up consisting of 10 minutes on a stationary bike, self selected static and dynamic warm-up. The participants were asked to perform the chest throw from an extended arm position directly in front of the chest before throwing the medicine ball using a self-selected shoulder retraction. After the warm-up, the kinematic signals were collected in each throwing position using four inertial measurement unit (IMU) sensors (Noraxon U.S.A. Inc., USA) were attached on both left and right upper arm and lower arm segments at 200 Hz. Prior to data collection, participant stood still in order to perform static calibration was performed based on recommendation of the manufacture. Participants were asked to perform five trials with 3 minutes rest between trials of medicine ball throws from chest level using three different throwing positions including 1) seated chest throw (SIT), 2) kneeling chest throw (KN), and 3) standing chest throw (ST) (Figure 1), all performed with a ballistic medicine ball weighing 5 kg (Ballistic Ball; Assess2Perform, Colorado, USA). The Ballistic Ball is simply a medicine ball with an internal IMU that lets it calculate velocity. Participants were randomly allocated to the three throwing positions in a counterbalanced order. All tests started by participant holding an embedded accelerometer medicine ball at shoulder level with full elbow extension. After receiving the signal “GO”, participants were instructed to throw the medicine ball as quick and powerful as possible. Five trials were performed and analyzed. Shoulder and elbow joint angles and velocity in the sagittal plane were obtained from MyoMotion MR3 software (Noraxon Inc., USA). The average of five trials were used for further analysis. Variabilities of UE during the tests were determined by the coefficient of variation (CV).

Statistical analysis

All statistical analyses were performed using jamovi software (version 2.3.3, https://www.jamovi.org). The assumption of data normality was examined using a Shapiro-Wilk test wand quantile-quantile (Q-Q) plots of the residuals. Mauchly's test of sphericity was used to confirm the assumption of sphericity and a Greenhouse Geisser correction was applied if violated. Data analysis was performed using a one way (condition) within subject repeated measures ANOVA was used to examine differences between the three throwing positions. Therefore, checking the assumption of homogeneity of variances is not required as there are no groups (i.e., not between subject).. If a significant difference between conditions was found, a post hoc test with a Least Square Difference (LSD) correction was applied to examine which conditions were significantly different to each other. Descriptive analysis (%CV) was used to interpret the variability in kinematic variables across the 3 medicine ball throwing positions. All data are reported as mean and standard deviation unless otherwise stated. The level of statistical significance was set at $p < 0.05$.

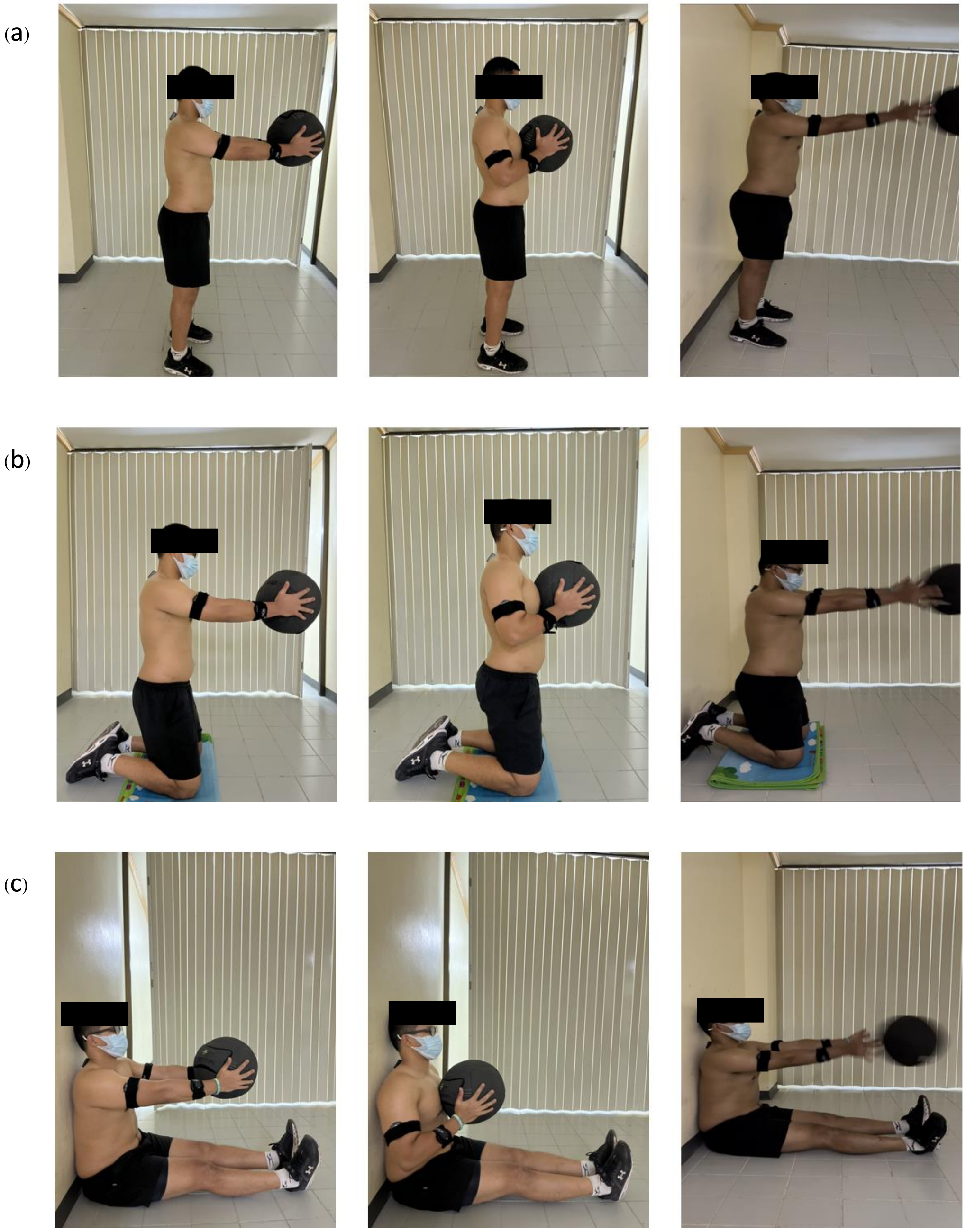

Figure 1 **(**a**)** Standing chest throw **(**ST**)** **(**b**)** Kneeling chest throw **(**KN**)** **(**c**)** Seated chest throw **(**SIT**).**

Results

Peak ball velocity was significantly different between conditions **(**p=0.026**)** with a higher peak ball velocity in the ST position compared with the SIT **(**p=0.049**)** and KN positions **(**p=0.028**).** There was no significant difference in peak ball power between the three medicine ball throwing positions **(**p=0.404; Table 1**).** Elbow ROM was not different across the three ball throwing conditions (p=0.980; Table 2), however, there was a significant difference in shoulder ROM. The shoulder ROM in the SIT position was significantly greater compared with the KN position (p<0.01; Table 2).

For UE movement variability, descriptive analysis showed that %CV was generally consistent for the shoulder and elbow ROM for kinematic variables across all conditions (Table 2; Figure 2 & 3).

Table 1 Mean ± standard deviation (SD) of peak medicine ball velocity and power among three different positions

Positions	ST	KN	SIT	P Value
Peak Ball Velocity (m/s)	5.2±0.5*	5.0±0.6***	5.0±0.5$^{*\ ***}$	0.026
Peak Ball Power (watt)	738±128	739±176	703±130	0.404

ST = Standing medicine ball test; KN = Kneeling medicine ball test; SIT = Seated medicine ball test; * indicates significant difference between the ST and KN position; ** indicates significant difference between the ST and SIT position; *** indicates significant difference between the KN and SIT position.

Table 2 Mean ± standard deviation (SD) and coefficient variation (CV) of shoulder and elbow flexion and extension, range of motion (ROM) and peak angular velocities of the three throwing position.

Kinematics variables	Positions					
	ST		KN		SIT	
	mean ± SD	CV	mean ± SD	CV	mean ± SD	CV
Shoulder ROM (deg)	68.92±9.1	13.24	76.80±8.0	10.41	68.16±5.8	8.51
Elbow ROM (deg)	107.47±6.9	6.50	105.98±7.6	7.21	170.7±6.1	5.67
Peak Shoulder angular velocity (deg/s)	228.23±16.6	7.28	257.48±19.3	7.51	302.12±23.9	7.93
Peak Elbow angular velocity (deg/s)	436.25±81.7	18.75	406.56±61.1	15.04	463.51±52.4	11.31

ST = Standing medicine ball test; KN = Kneeling medicine ball test; SIT = Seated medicine ball test

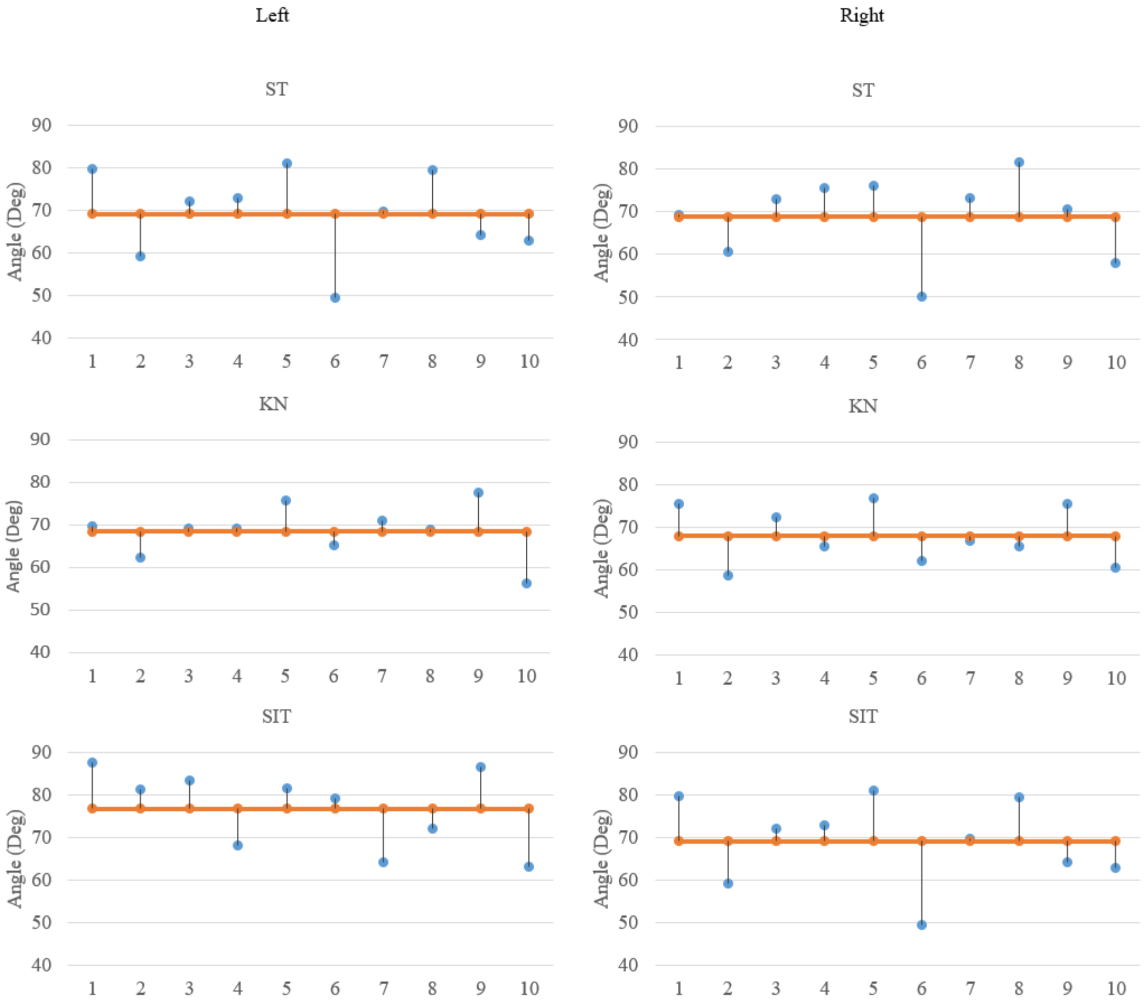

Figure 2 The data points of shoulder ROM with mean (horizontal line) and standard deviation (average of vertical lines) illustrated in each throwing position. The graphs on the left column represent the left shoulder angle and the graphs on the right column represent the right shoulder angle.

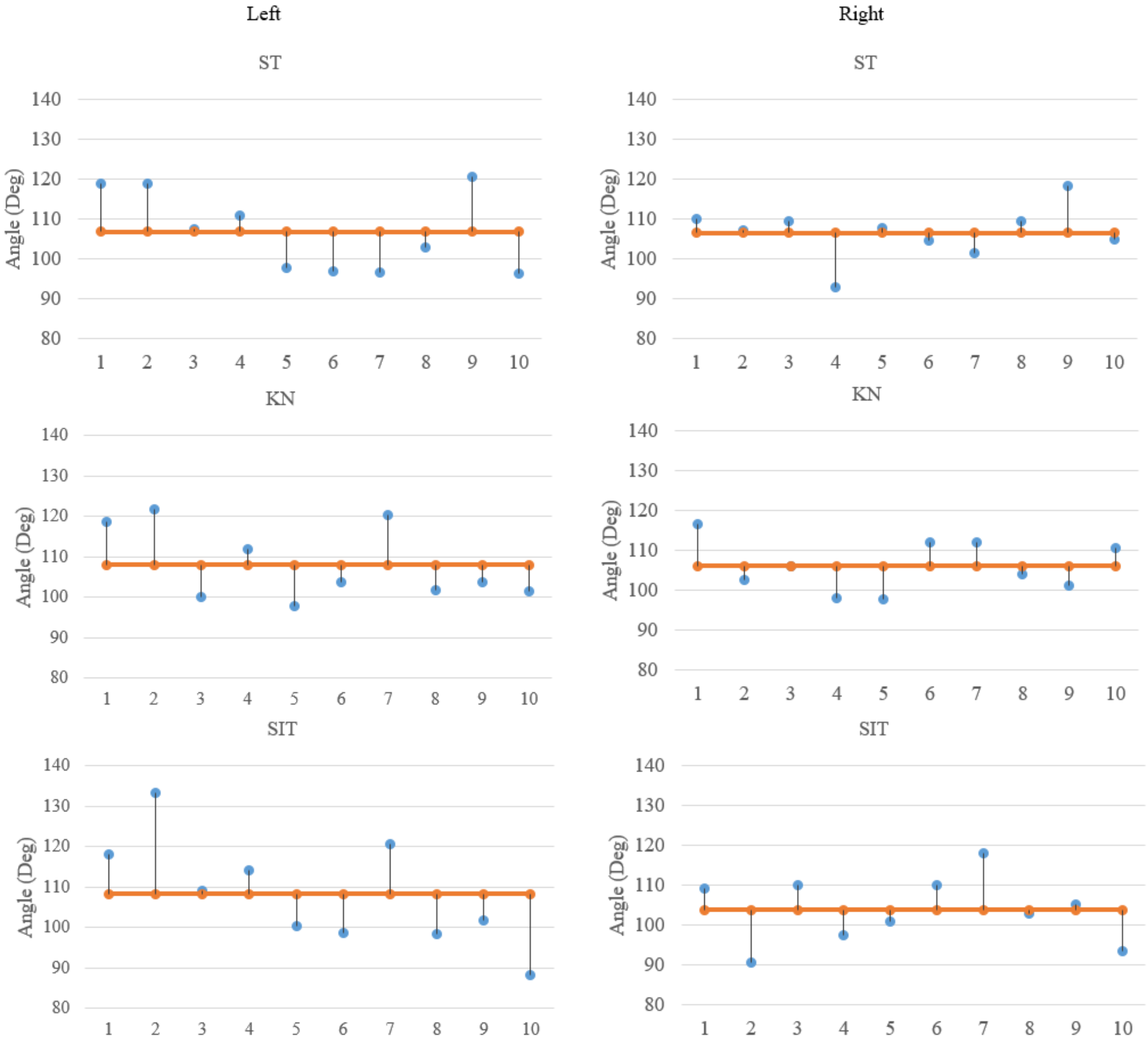

Figure 3 The data points of elbow angle with mean (horizontal line) and standard deviation (average of vertical lines) illustrated in each throwing position. The graphs on the left column represent the left elbow angle and the graphs on the right column represent the right elbow angle**.**

Discussion

The main findings from the present study showed that there was a greater peak ball velocity in the ST position compared with the SIT and KN throwing positions. We also observed a greater shoulder ROM in the SIT position compared with the KN throwing position. Descriptive analysis also indicated a degree of variability in measured kinematic variables between the three medicine ball positions.

The greater ball velocity observed in the ST position (Table 1) may be partly explained by the constraint of the body in the standing position compared with throwing a medicine ball in the kneeling and sitting positions, respectively. A previous study (Chen et al, 2016) comparing different positions during overarm throwing suggested that in contrast to ball velocities recorded during sitting and trunk fixed positions (when the lower limbs are constrained), participants increased their ball velocity by compensating via moving their trunk forwards in the standing position(15).

We also observed shoulder ROM in the SIT position to be greater compared with the KN (Table 2). It is difficult to provide an explanation as to why shoulder ROM in the SIT position was markedly greater than when kneeling. This is because shoulder ROM would expected to be less then when kneeling due to ROM being restricted when leaning against a wall (Figure 1). However, a possible explanation is due to the size of the medicine ball making early contact with the chest in each position, thus, restricting the ROM at the shoulder. Therefore, studies utilizing smaller sized medicine balls that contain accelerometers should be a focus of future work.

The variability (%CV) of kinematic parameters obtained from the 5 throwing trials were generally consistent across the different medicine ball throw positions (Table 2). The %CV values (averaged across left and right sides of the body) were all below 20% indicating that there was relatively little variability across the measured kinematic variables. Bartlett et al., 2007 stated that consideration reduced variability leads to better performance has been a key principle for learning new skills(15). Whereas previously it was believed that there are optimal movement patterns which athletes should follow to achieve the best performance, it has now been shown that functional movement variability exists even in elite athletes who are well trained(15). The movement variability could represent performer adaptations to facilitate optimizations in coordination patterns(16, 17). Nevertheless, lesser variability is still better in term of controlling the factors that may affect to the outcome of UE plyometric test.

It is possible that ST has a greater number of joints involved in the kinematics chain, providing proximal to distal joint movement, than KN and SIT and these were limited by many stable joints so both KN and SIT may produce less joint velocity leading to peak ball velocity than ST. Meanwhile KN and SIT, with the limited joint involvement resulted in less peak ball velocity. This limitation, however, may help to identify compensatory movement during medicine ball throw like trunk movement, flexion and extension, that may support the kinematics chain by increasing shoulder or elbow ROM.

The reason is that peak ball velocity showed higher peak ball velocity in the ST position compared with the SIT and KN positions because of the kinematics chain. In terms of ball power, no significant differences were found between the three medicine ball throw positions. This may be attributed to the attempted compensation of the involved muscle activity during throwing, which unfortunately is beyond the examined factors in this study. Furthermore, peak ball power, as explained by the equation (P = F x s/t), could not be significantly affected as participants produce a similar force and arm moving displacement thereby producing similar outputs in power during eccentric and concentric contraction, such as that in the plyometric concept.

Limitations of this study

However, the current study has limitations as the data collected are only of male athletes of Mahidol university of age between 18 and 25 years. Female was excluded from this study to eliminate any sex-related differences, which may have lowered the variability in the outcomes of our sample.

Conclusion

The UE kinematics obtained from different medicine ball chest-throw positions were generally similar irrespective of the throw position. Nevertheless, the ST position showed that a greater peak ball velocity could be obtained compared with the KN and SIT positions, respectively. Paradoxically, shoulder ROM was greater in the SIT position, thus, it is suggested that the selection of small medicine balls (containing accelerometers) should be considered when interpreting kinematic data to make inferences related to throw performance. There appeared acceptable variability in kinematic variables across the different throwing positions, this suggests that reliable measures of medicine ball plyometric performance may be obtained using the ballistic medicine ball. This will enable the practitioner to better individualize their strength and conditioning program to optimize outcomes for the basketball players.

Acknowledgements

This authors would like to acknowledge the facilities and assistance of College of Sports Science and Technology, Mahidol University. I would like to acknowledge and give my warmest thanks to my supervisor (Parunchaya Jamkrajang) who made this stages of writing my project. This work supported by the 60th Year Supreme Reign of His Majesty King Bhumibol Adulyadej Scholarship, Mahidol University, Thailand.

References

1. Bobbert MF, Gerritsen KG, Litjens MC, Van Soest AJ. Why is countermovement jump height greater than squat jump height? Medicine and science in sports and exercise. 1996;28(11):1402-12.
2. Komi PV, Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. Medicine and science in sports. 1978;10(4):261-5.
3. Cavagna GA, Dusman B, Margaria R. Positive work done by a previously stretched muscle. Journal of applied physiology. 1968;24(1):21-32.
4. Bosco C, Komi PV, Ito A. Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiologica Scandinavica. 1981;111(2):135-40.
5. Bosco C, Komi PV. Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. Acta Physiologica Scandinavica. 1979;106(4):467-72.
6. Bobbert MF. Drop jumping as a training method for jumping ability. Sports medicine. 1990;9(1):7-22.
7. Komi PV. Stretch-shortening cycle. Strength and power in sport. 2003;2:184-202.
8. Read MM, Cisar C. The influence of varied rest interval lengths on depth jump performance. Journal of strength and conditioning research. 2001;15(3):279-83.
9. Moore LH, Tankovich MJ, Riemann BL, Davies GJ. Kinematic analysis of four plyometric push-up variations. International Journal of Exercise Science. 2012;5(4):334.

10. Lockie RG, Dawes JJ, Orr RM, Stierli M, Dulla JM, Orjalo AJ. Analysis of the Effects of Sex and Age on Upper- and Lower-Body Power for Law Enforcement Agency Recruits Before Academy Training. Journal of strength and conditioning research. 2018;32(7):1968-74.

11. Roe G, Shaw W, Darrall-Jones J, Phibbs PJ, Read D, Weakley JJ, et al. Reliability and Validity of a Medicine Ball–Contained Accelerometer for Measuring Upper-Body Neuromuscular Performance. The Journal of Strength & Conditioning Research. 2018;32(7):1915-8.

12. Abbott JC, Wagle JP, Sato K, Painter K, Light TJ, Stone MH. Validation of Inertial Sensor to Measure Barbell Kinematics across a Spectrum of Loading Conditions. Sports (Basel, Switzerland). 2020;8(7).

13. Jamkrajang P, Mawhinney C, Limroongreungrat W. Variability of hip and knee angles during a-30 minute run in healthy runners. Journal of Sports science and technology. 2020 (Vol. 20 No. 2 (2020)).

14. Cronin JB, Owen GJ. Upper-body strength and power assessment in women using a chest pass. Journal of strength and conditioning research. 2004;18(3):401-4.

15. Chen C-Y, Tsai Y-Y, Hung J-C, Su T-Y, Chen T-Y, editors. Effects on postural constraints on overarm throwing. 2016.

16. Bartlett R, Wheat J, Robins M. Is movement variability important for sports biomechanists? Sports biomechanics. 2007;6(2):224-43.

17. Langdown B, Bridge M, Li F-X. Movement variability in the golf swing. Sports biomechanics / International Society of Biomechanics in Sports. 2012;11:273-87.