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The Influence of Self-Selected Protective Equipment on Kinematics in Youth Lacrosse Players

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Abstract

Background: Lacrosse is a rapidly growing sport in the United States, especially in male, youth athletes, and these athletes do not always wear equipment that is the correct size and fit when competing. The purpose of this study was to examine differences in position and angular velocity kinematics in male youth lacrosse athletes performing three different lacrosse shots: overhand, sidearm, and underhand with and without self-selected protective equipment.

Methods: Ten male, youth lacrosse players (12.88 ± 1.95 years; 4.90 ± 1.45 years of experience, 163.55 ± 19.9 cm; 48.59 ± 15.82 kg) participated. Participants performed five of each lacrosse shot (overhand, sidearm, and underhand) with personal protective equipment and then five of each lacrosse shot without personal protective equipment. Three repeated measures ANOVA tests with an alpha level set *a priori*at $p < 0.05$ were conducted.

Results: Results of the study revealed significant main effects of the Gear condition for the sidearm ($F_{1,9} = 7.43$, p = 0.023, $\eta^2 = 0.452$) and underhand shot ($F_{1,9} = 8.93$, p = 0.015, $\eta^2 = 0.498$). Post-hoc testing revealed decreased trunk extension and lateral flexion position kinematics, as well as decreased trunk, hip, dominant humerus, dominant forearm, and dominant hand angular velocities when performing sidearm and underhand shots while wearing protective equipment.

Findings & Interpretations*:* These findings revealed that wearing self-selected protective equipment resulted in altered shot kinematics. Thus, future research should investigate the relationship of altered shot kinematics and injury potential in male youth lacrosse players.

Introduction

There has been a dramatic increase in lacrosse participation within the United States since the turn of the millennium National participation in lacrosse ranging from youth programs to post-college careers has increased from 253,931 athletes in 2001 to 826,033 athletes in 2016; an approximate 325% increase [1]. Of the 826,033 active lacrosse players, 770,404 play at the youth and high school levels, and of the youth and high school athletes, 473,094 are male [1]. Likewise, the National Collegiate Athletic Association (NCAA) has reported marked increases in lacrosse participation at the collegiate level. NCAA Men's Lacrosse has increased from 211 teams and 6,551 athletes in 2001 to 362 teams and 13,446 athletes in 2016 [2].

Just as the sport of lacrosse has evolved, so has the fit and function of protective equipment. The proper fit and function of football helmet and shoulder pads [3-6], as well as hockey pads [5,7] have been extensively researched for the development of mandated standards of fit. Current standards for shoulder pad fitting for these sports are to protect the joints that comprise the shoulder (i.e., glenohumeral joint, acromioclavicular joint, and sternoclavicular joint) while allowing for adequate range of motion [5,8]. While research has investigated the parameters for proper fitting and function of football and hockey shoulder pads, data are lacking describing the proper fit of lacrosse shoulder and elbow pads. Data regarding protective equipment in lacrosse has previously focused on helmet design [7,9-11].

Despite the absence of data regarding the fit of lacrosse shoulder and elbow pads, the US Lacrosse Organization developed an instructional guide for the proper fit of equipment [1]; however, lacrosse shoulder and elbow pad fitting is typically the responsibility of the parent or athlete, who may not be trained in proper shoulder and elbow pad fitting. In the case of college or professional athletes, equipment fitting is the responsibility of an athletic trainer or equipment specialist, as they are trained in the proper fitting and inspection of football and hockey shoulder pads [5]. However, because athletic trainers and equipment specialists do not typically work closely with youth athletes,

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Table 1: Overhand shot descriptive data (means ± standard error).

Kinematic Variable (°)	Group	1	2	3	4	5
Pelvis Rotation	Equipment	-70+7	-51+5	-5+4	2+4	10+4
	No Equipment	-72 ± 7	-51 ± 6	-5 ± 4	2 ± 3	10 ± 3
Trunk Extension	Equipment	4+2	0+2	-15+2	-21+3	-22+4
	No Equipment	8 ± 2	3 ± 2	-13 ± 3	-21± 3	-22 ± 3
Trunk Lateral Flexion	Equipment	6+3	-2+3	-12+3	-18+3	-18+2
	No Equipment	3 ± 3	-2 ± 3	-10 ± 4	-16 ± 5	-16 ± 4
Trunk Rotation	Equipment	-90 ± 7	-77 ± 7	-5 ± 5	33 ± 4	50 ± 5
	No Equipment	-89+6	-73+7	-5+6	32+5	49+6

Trunk: Extension (+), Flexion (-), Trunk Lateral Flexion: Right (+), Left (-) Trunk Rotation: Right (-), Left (+) and Pelvis Rotation: Right (-), Left (+). 1=Phase 1; 2=Phase 2; 3=Phase 3; 4=Phase 4; 5=Phase 5.*-significance, $p < 0.05$.

Table 2: Sidearm shot descriptive data (means ± standard error).

Kinematic Variable	Group	1	2	3	4	5
Pelvis Rotation	Equipment	-71+6	-52+5	-4+5	1+4	7+5
	No Equipment	-69 ± 6	-51 ± 5	-3 ± 4	3 ± 3	10 ± 4
Trunk Extension	Equipment	3+3	4+3	-3+3	-7+4	-8+4
	No Equipment	7 ± 2	7 ± 3	-2 ± 3	-7 ± 3	-7± 3
Trunk Lateral Flexion	Equipment	19+3	17+4	12+3	6+4	3+3
	No Equipment	16 ± 3	17 ± 4	14 ± 3	9 ± 4	4 ± 3
Trunk Rotation	Equipment	-87 ± 8	-74 ± 6	-5 ± 5	28 ± 5	46 ± 5
	No Equipment	-87+6	-73+7	-4+6	30+6	49+6

Trunk: Extension (+), Flexion (-), Trunk Lateral Flexion: Right (+), Left (-) Trunk Rotation: Right (-), Left (+) and Pelvis Rotation: Right (-), Left (+). 1=Phase 1; 2=Phase 2; 3=Phase 3; 4=Phase 4; 5=Phase 5.*-significance, $p < 0.05$.

Table 3: Underarm shot descriptive data (means ± standard error).

Kinematic Variable (°)	Group	1	2	3	4	5
Pelvis Rotation	Equipment	-69+6	-55+6	-12+5	-4+5	5+6
	No Equipment	-71± 6	-54 ± 5	-11 ± 5	-1 ±5	7 ± 5
Trunk Extension	Equipment	1+3*	6+4*	3+4	-1+5	-5+5
	No Equipment	6 ± 3*	9 ± 4*	6 ± 5	0 ± 5	-2 ± 5
Trunk Lateral Flexion	Equipment	23+3	27+4	26+3*	24+3*	16+3
	No Equipment	23±3	28 ± 4	29 ± 3*	28 ± 3*	18 ± 3
Trunk Rotation	Equipment	-81 ± 9	-74 ±10	-15 ± 8	19 ± 6	39 ± 6
	No Equipment	-86+8	-76+9	-15+9	20+7	41+5

Trunk: Extension (+), Flexion (-), Trunk Lateral Flexion: Right (+), Left (-) Trunk Rotation: Right (-), Left (+) and Pelvis Rotation: Right (-), Left (+). 1=Phase 1; 2=Phase 2; 3=Phase 3; 4=Phase 4; 5=Phase 5.*-significance, $p < 0.05$.

equipment fitting becomes the responsibility of the players and their parents/guardians. Thus, it is important for lacrosse players and their parents/guardians to understand the biomechanical implications of properly fitted equipment on maximizing performance while providing safety. Protective equipment is designed for the safety and well-being of the athlete; however, improperly fitted equipment can be detrimental to sport performance [12,13].

Improperly fitted equipment may predispose injury due to such factors as restrictied range of movement or inadeaquate protection thus resulting in altered movement kinematics. Therefore, the purpose of this study was to examine differences in position and angular velocity kinematics in male youth lacrosse athletes performingof three different lacrosse shots: overhand, sidearm, and underhand with and without self-selected protective equipment. The position kinematic variables of interest included: trunk extension, trunk lateral flexion, trunk rotation, and pelvis rotation. Angular velocities of interest included: trunk angular velocity, hip angular velocity, dominant humerus angular velocity, dominant forearm angular velocity, and dominant handangular velocity. It was hypothesized that shooting without wearing equipment would likely result in uninhibited range of motion allowing for the use of preferred shooting mechanics. Specifically, wearing self-selected protective equipment (helmet, shoulder and elbow pads, and gloves) would result in pathomechanics, such as altered trunk and pelvis position, as well as altered trunk and upper extremity angular velocities, which may affect performance and predispose these athletes to sub-optimal performance and injury.

Participants

Ten male, youth lacrosse players (12.88 ± 1.95 years; 4.90 ± 1.45 years of experience, 163.55 ± 19.9 cm; 48.59 ± 15.82 kg) volunteered to participate. To be included in this study, the participant was required to be a male, youth lacrosse player, with at least one year of competitive lacrosse experience playing at either the midfield or attack man positions, and free from injury for the past six months. Local youth coaches assisted in the recruitment of participants to ensure the sample was experienced in their on-field position. Testing was conducted in the Sports Medicine & Movement Laboratory at Auburn University. The University's Institutional Review Board approved all testing protocols. Upon participant arrival, parents and participants were debriefed on the testing procedures and parental consent and minor assent were obtained.

Procedures

The MotionMonitor® (Innovative Sports Training, Chicago, IL) synced with an electromagnetic tracking system (Track Star, Ascension Technologies Inc., Burlington, VT) was used to collect all data. Magnitude of error in determining the position and orientation of the electromagnetic sensor within a calibrated world was less than 0.01 m [14]. A series of 15 electromagnetic sensors (Track Star, Ascension Technologies Inc., Burlington, VT) were affixed to the following anatomical locations: [1] seventh cervical vertebra (C7) spinous process; [2] pelvis at the first sacral vertebra (S1); [3-4] flat, broad portion of the acromion of the scapula, [5-6] bilateral deltoid tuberosity of the humerus, [7-8] bilateral wrist on the dorsal aspect of the wrist 2 cm superior to the radial and ulnar styloid processes,

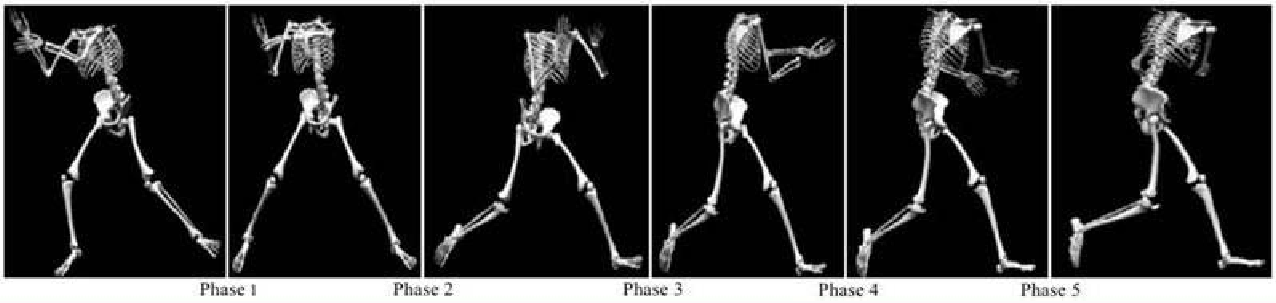


Figure 1: Phases of Lacrosse Shot.

[9] dominant hand on the dorsal aspect of the third metacarpal, [10-11] bilateral midpoint of the lasteral aspect of the femur, [12-13] bilateral shank centered between the head of the fibula and the lateral malleolus, and [14-15] bilateral feet on the dorsal aspect of the second metatarsal bone.

Student researchers trained in palpation, location, and application techniques affixed the sensors. Sensors were secured to the skin using generic double-sided tape coupled with Cover Roll (BSN Medical, Hamburg Germany) and powerfast cohesive tape (Andover Healthcare, Salisbury, MA) to ensure the sensors remained stationary throughout the testing process. An additional sensor attached to a stylus was used to digitize the trunk and upper and lower extremity bony landmarks to create a skeleton model of the participant [15-17]. Participants stood in an anatomical neutral position during digitization to accurately identify bony landmarks. A link segment model was developed through digitization of joint centers for the ankle, knee, hip, shoulder, elbow, wrist, twelfth Thoracic vertebra (T12) to the first Lumbar vertebra (L1), and the seventh Cervical vertebra (C7) to the first Thoracic vertebra (T1). The spinal column was defined as the digitized space between adjacent spinous processes, and the ankle and knee joints were defined as the midpoint between the medial and lateral malleoli and the midpoint between the digitized medial and lateral femoral condyles, respectively [14]. The shoulder and hip joints were estimated using the rotation method [14,18]. This method has been previously reported to provide valid positional data for the shoulder and hip joints [18]. The shoulder joint center was calculated from rotation of the humerus relative to the scapula, and the hip joint center was calculated from the rotation of the femur relative to the pelvis. Varation in the measurement of the joint center (root mean square) was accepted for values less than 0.003 m [14]. After digitization, the participant was given self-determined time to warm up (approximately five minutes) using just their personal gloves and lacrosse stick until they deemed themselves ready to participate at maximal effort. Participants shot a standard-size lacrosse ball (5.0 oz) into a regulation-sized lacrosse goal (182.88 cm high x 182.88 cm wide x 213.4 cm long, Maverik Lacrosse, New York City, NY) positioned a distance of 5 meters. Participants were required to perform fifteen maximum effort overhand, sidearm, and underhand shots accurately on the goal, and they were instructed to land with their stride foot on the force plate. A successful trial included an accurate shot into the goal, as well as landing on the force plate. The trials were non-randomized with the participant performing five overhand shots, then five sidearm shots, and lastly five underhand shots without wearing protective equipment. Gloves were used in both conditions of protective equipment and no equipment to allow for familiarity and hand placement on the stick to ensure desired shot mechanics. Once all data were collected for the fifteen shots using only their gloves and stick, the participant then wore all protective equipment they would typically wear in a game (helmet, shoulder and elbow pads, and gloves), with the exception of a mouthguard and a cup, and repeated the same protocol. Previous research by Mercer & Nielson (2013) divided the lacrosse shot into six major phases: 1) approach, 2) crank-back, 3) stick acceleration, 4) stick deceleration, 5) follow through, and 6) recovery [19]. Due to sensor distortion in the beginning of each trial as a result of the participant being outside of the capture volume prior to the shot, the phases were restructured and only five phases were utilized, as some components of the recovery phase did not apply to the situation of the lab experiment (Figure 1). Phase 1 was between the first instance of drive (i.e., non-stride) foot contact and the first instance of stride foot contact onto the force plate. Phase 2 was between stride foot contact to maximum elbow flexion of the top (dominant) arm. Phase 3 was between maximum elbow flexion of the top (dominant) arm to ball release. Because we were unable to track the ball and stick within the electromagnetic system, ball release was estimated as the midpoint between maximum elbow flexion and maximum elbow extension of the top (dominant) arm. One researcher familiar with lacrosse shooting technique determined ball release. This method has been previously utilized in overhand throwing literature, but has yet to be validated [14,20,21]. Phase 4 was between ball release to maximum elbow extension of the top (dominant) arm. Lastly, Phase 5 was between maximum elbow extension to the end of trunk rotation (largest value of trunk rotation) in the transverse plane.

Statistical Analysis

Data were analyzed using Statistical Package for Social Science (SPSS) software (version 23; SPSS Inc., Chicago, IL, USA). Trunk extension, trunk lateral flexion, trunk rotation, pelvis rotation, trunk angular velocity, hip angular velocity, dominant humerus angular velocity, dominant forearm angular velocity, and dominant hand wrist angular velocity kinematic variables were assessed at each phase of the shooting motion for both conditions of wearing protective equipment and not wearing protective equipment. Three 2 (Equipment) x 5 (Phase) x 9 (Variable) repeated measures analysis of variance (RM ANOVA) tests were conducted; one for each shot type. Mauchly's Test of Sphericity was used to determine sphericity of the data, and was adjusted using a Greenhouse-Geisser correction when necessary. The alpha level was set *a priori* at $p < 0.05$ using Bonferroni corrections for all analyses.

Results

For all shot types, there were a significant interactions for the Phase and Variable measures: overhand shot ($F_{32,288}$= 78.84, p < 0 .001,

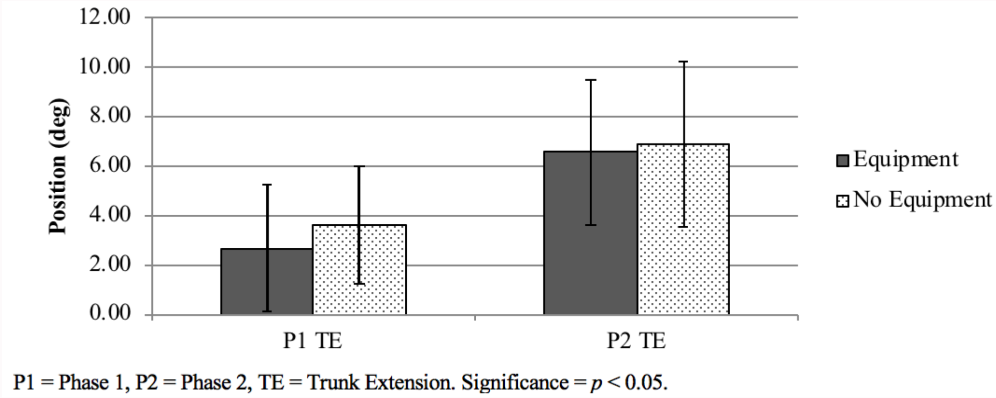
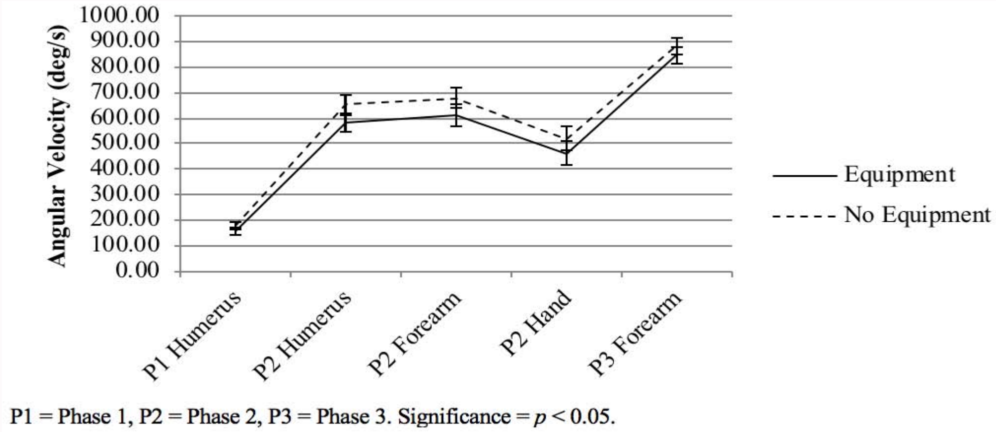


Figure 2: Significant differences in position kinematics at different phases between the equipment and no equipment conditions for the sidearm shot.



Figures 3: Significant differences in angular velocity at different phases between the equipment and no equipment conditions for the sidearm shot.

η^2 = 0.898), sidearm shot ($F_{32,288}$ = 75.58, p < 0.001, η^2 = 0.894), and underhand shot ($F_{32,288}$ = 71.98, p < 0.001, η^2 = 0.889). However, these results are not meaningful within the scope of this study as one would expect there to be significant kinematic differences across phases and variables given their exclusive relationship from one another. Therefore, only significant main effects and interactions including the Equipment condition are practical for understanding the results within the scope of this study.

Overhand Shot

All descriptive kinematic data are presented in (Table 1). There were no significant main effects of Equipment in the overhand shot ($F_{1,9}$=0.004, p > 0.05, η^2 < 0.001).

Sidearm Shot

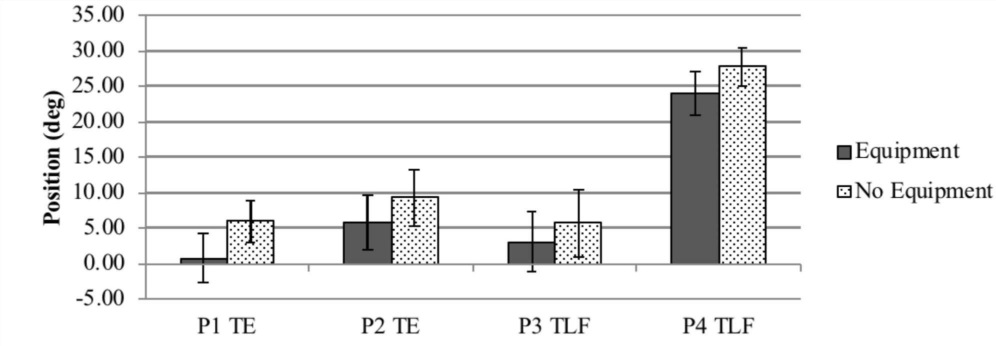
All descriptive kinematic data are presented in (Table 2). There were significant main effects of Equipment in the sidearm shot ($F_{1,9}$ =7.43, p = 0.023, η^2 = 0.452). Post-hoc dependent samples t-tests found significant mean differences between theequipment conditions for trunk extension during Phase 1 (t(9) = -3.53, p = 0.006), trunk extension during Phase 2 (t(9) = -2.35, p = 0.044) (Figure 2), dominant humerus angular velocity during Phase 1 (t(9)= -2.31, p = 0.046), dominant humerus angular velocity during Phase 2 (t(9)= -3.78, p = 0.004), dominant forearm angular velocity during Phase 2 (t(9)= -4.43, p = 0.002), dominant wrist angular velocity during Phase 2 (t(9) = -3.61, p = 0.006), and dominant forearm angular velocity during Phase 3 (t(9= -3.19, p =0.011) (Figure 3).

Underhand Shot

All descriptive kinematic data are presented in Table 3.There were significant main effects of Equipment in the underhand shot ($F_{1,9}$= 8.93, p = 0.015, η^2 = 0.498). Post-hoc dependent samples t-tests found significant mean differences between the Equipment conditions for trunk extension during Phase 1 (t(9)=-5.00, p = 0.001), trunk extension during Phase 2 (t(9) = -3.05, p =0.014), trunk lateral flexion during Phase 3 (t(9)= -3.10, p = 0.013),trunk lateral flexion during Phase 4 (t(9)=-3.01, p = 0.015) (Figure 4), hip angular velocity during Phase 1 (t(9)= -2.60, p = 0.029), trunk angular velocity during Phase 2 (t(9) = -3.20, p = 0.011) hip angular velocity during Phase 2 (t(9)= -3.22, p = 0.011), dominant humerus angular velocity during Phase 2 (t(9) =-2.94, p = 0.017), dominant forearm angular velocity during Phase 2 (t(9)= -5.75, p < 0.001), shooting wrist angular velocity during Phase 2 (t(9)= -2.59, p = 0.029), dominant hand wrist angular velocity during Phase 3 (t(9) = -2.44, p = 0.038), and trunk angular velocity during Phase 4 (t(9) = -2.45, p = 0.037) (Figure 5).

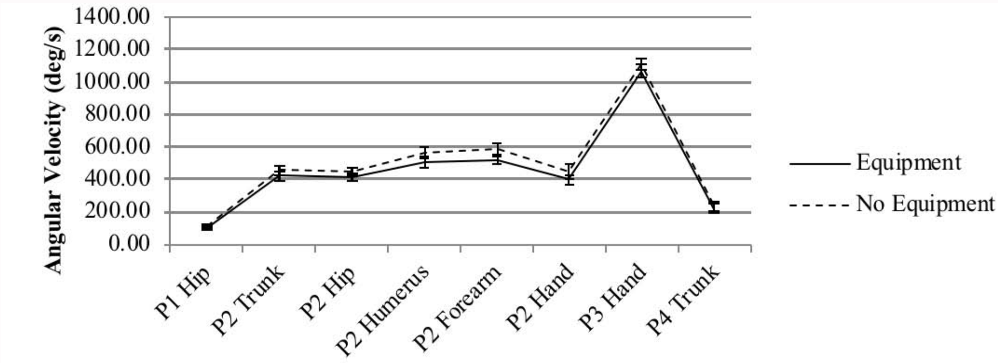
Discussion

The purpose of this current study was to examine the effect differences in position and angular velocity kinematics in male youth lacrosse athletes performing three different lacrosse shots: overhand, sidearm, and underhand with and without self-selected protective equipment. The results of this study revealed significant differences in trunk positioning during Phases 1 and 2 of the sidearm and underhand shots, as greater degrees of trunk extension were



P1 = Phase 1, P2 = Phase 2, P3 = Phase 3, P4 = Phase 4, TE = Trunk Extension, TLF = Trunk Lateral Flexion. Significance = $p < 0.05$.

Figure 4: Significant differences in position kinematics at different phases between the equipment and no equipment conditions for the underhand shot.



P1 = Phase 1, P2 = Phase 2, P3 = Phase 3, P4 = Phase 4. Significance = $p < 0.05$.

Figures 5: Significant differences in angular velocity at different phases between the equipment and no equipment conditions for the underhand shot.

present when the participatns perforem without wearing protective equipment. These findings are similar with previous findings that found lacrosse shooting heavily relies on trunk extension [14]. Greater trunk extension in the beginning phases of the sidearm and underhand shot, as presented in the current study, could possibly suggest optimal energy storage to be used as trunk flexion occurs throughout the shot. This principle has been investigated in the tennis serve, with previous research suggesting that trunk extension and rotation are important components of performing a powerful serve [22,23]. These researchers claim that muscle pre-tension and elastic energy storage in the trunk and lumbar extensors allow tennis players to perform a more powerful serve as they transition into trunk flexion throughout the serve [22,23]. This notion is similar to lacrosse research that believes trunk extension may be vital for efficient energy storage and transfer if performed in the initial phases before transitioning into trunk flexion in the later phases of the lacrosse shot [14]. Therefore, it is postulated that performing the sidearm and underhand shots without wearing protective equipment may allow the participant to have greater energy storage in the trunk flexors during the beginning phases of the lacrosse shot and transfer that energy throughout the shot resulting in a more powerful ball release. Conversely, these findings could suggest that wearing improperly fitted protective equipment could limit an athlete's energy storing capabilities through limited range of motion, thereby negatively impacting performance. Similarly, there were significant differences regarding angular velocities between wearing protective equipment and not wearing protective equipment. Specifically, the not wearing protrective equipment resulted in greater angular velocity of the trunk, hip, humerus, forearm, and wrist when performing the sidearm and underhand shots. Angular velocities of the trunk, hip, humerus, forearm, and hand were most different during Phases 1, 2, and 3. Phase 1 is from drive foot contact to stride foot contact, thereby focusing on the footwork portion of the shot. Previous research has deemed the lower extremities as the main force generators for the kinetic chain in overhead throwing, as well as the force transducers up the chain into the pelvis and trunk [3,24]. Furthermore, it has been reported that a 20% decrease in kinetic energy from the hip and trunk to the throwing arm required a 34% increase in shoulder rotational veloctiy to produce the same amount of force at the hand during throwing [24]. This illustrates that a loss in transferred energy from the lower extremities places a great burden on the musculature of the upper extremities to produce a comparable force during an overhead throw. This notion agrees with the findings of Bird & Steinhauser (1997), who found that ball velocity during an overhead throw increased as leg and trunk contribution increased [25]. Similarly, Saeterbakken et al (2011) found that increased trunk strength and stability increased maximal throwing velocity in high-school handball players [26]. It is possible that higher trunk and upper extremity velocities in the Phase 1 could be reflective of greater force production in the lower extremities and more efficient energy transfer. Future research should seek to describe lower extermity angular velocities in lacrosse shooting to explore this possiblity. Phase 2, of the lacrosse shot, is from stride foot contact to maximum shooting elbow flexion, thereby assessing the cocking portion of the shot. Phase 3 is from maximum shooting elbow flexion to ball release, thereby assessing the acceleration portion of the shot. Similar to a baseball pitch or overhand throw, the cocking phase in a lacrosse shot utilizes the stretch-shortening cycle to produce a concentric contraction in the acceleration phase [27,28] in a proximal-to-distal sequencing pattern [29]. Eccentric stretching of a muscle and tendon followed quickly by a concentric contraction has been shown to increase force output of the muscle transmitted through the tendon [30]. With lacrosse, Mercer & Nielson (2013) believe that greater elbow flexion velocities during the cocking phase of the lacrosse shot yield a greater shot velocity due to the principles of the stretch-shortening cycle [19]. They suggested that peak elbow flexion serves as a counter-movement to peak elbow extension during the acceleration phase, thereby maximizing ball velocity during ball release [19].

Previous research found that greater pelvis and trunk rotational velocities were consistent with greater ball velocities [31]. More specifically, they claim that optimal rotation of the pelvis and trunk for energy transfer occurs during the cocking and acceleration phases of an overhand throw [31]. These principles suggest that higher angular velocities in Phase 2 may be consistent with greater eccentric stretching and higher angular velocities in Phase 3 may be consistent with greater concentric contractions. These two situations posit the notion that a more forceful and higher velocity shot can be produced by lacrosse athletes performing sidearm and underhand shots while not wearing protective equipment compared to wearing self-selected protective equipment.

While these participants may compete in their self-selected protective equipment, it is possible that the specific type or size of equipment is not allowing them to optimize performance. With lower mean values reported for all position and velocity kinematics while wearing protective equipment, it is possible that self-selected protective equipment in these participants inhibited their abilities to optimally move through a full range of motion and utilize the stretch-shortening cycle in the trunk and upper extremities when executing sidearm and underhand lacrosse shots. This may have a negative impact on several components of lacrosse shooting as they relate to potential injury. From a biomechanical perspective, slower velocities in the trunk and upper extremities when performing an eccentric movement may result in a loss of stored elastic potential energy in the hip and trunk musculature. Loss of energy will impose an increased demand placed on smaller upper extremity (scapular, shoulder, and forearm) muscles to concentrically contract with greater velocities to maintain a high shot speed [24,25]. From a sport perspective, the decrease in velocities in the trunk and upper extremities slows the athlete's time to adequately setup for their shot, thereby increasing the time that they are vulnerable to physical burdens from a defensive player. Impact from a defensive player can cause acute injury to an athlete as well, therefore quick and efficient movements in lacrosse are vital. In addition, slowed segmental velocities can result in a slower ball release speed [25,31], which is undesirable when attempting to produce a high velocity shot against a goaltender.

Limitations in this study include the small sample size. The study was performed directly following a competitive youth lacrosse season, therefore participant recruitment was sparse; however, it did ensure physical readiness of the participants used in the study. Another limitation is that because we were unable to digitize the ball and lacrosse stick to track their movements through the shot, ball release and stick position were estimated using the animation from the participants' digitized skeletons.

Conclusion

The findings from this study suggest that self-selected protective equipment worn by youth lacrosse players may negatively impact shot kinematics. Although this study found decreased trunk extension during the beginning phases of the shot and decreased angular velocities throughout the shot while wearing protective equipment, these findings do not aim to dismiss the importance and safety of lacrosse equipment or suggest that the sport should be performed without protective equipment. Properly fitted protective equipment should allow for protection of the shoulder and elbow joints while allowing for adequate range of motion and movement through a sport-specific task [5,8].

Currently, standards for proper lacrosse fitting are mere suggestions, without scientific data to support the fitting guidelines for parents and youth. Despite the release of a fitting guide by the US Lacrosse Organization, further steps should be taken to ensure proper fit and function of lacrosse equipment. It is possible that current protective equipment designs may affect the degrees of freedom in various anatomical joints, thus this research may prove useful for further research to create and develop newer, more functional lacrosse equipment that is sleeker and allows for full range of motion.

Lastly, as new equipment takes substantial time to develop, there may be methods that can be used with current equipment to decrease likelihood for injury. While practicing and competing in a contact sport without proper protective equipment is contraindicated, it may prove useful for the preliminary shooting and passing portion of lacrosse practice and competition warm-ups to be performed without equipment to decrease the amount of time under which the athlete's trunk and upper extremities may be subjected to altered kinematics and angular velocities prior to competition.

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