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The effectiveness of men's lacrosse shoulder pads in the attenuation of linear impact forces

by

Ryan S. Dambach

Submitted in Partial Fulfillment of the
Requirements for the Master of Science in Exercise Science Degree

Kinesiology Department

STATE UNIVERSITY OF NEW YORK COLLEGE AT CORTLAND

May 2018

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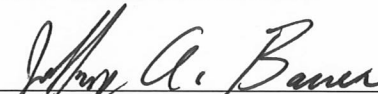
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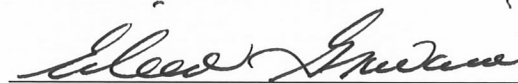
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ABSTRACT

BACKGROUND/PURPOSE: Men's lacrosse is a sport that is growing in popularity. The mandatory shoulder pads have no limit of use standards and are rarely studied. The purpose of the study was to measure peak impact force (IF) of new and used lacrosse shoulder pads.

METHODS: Six lacrosse shoulder pads, three new models (Warrior MPG 8.0 shoulder pad, STX Jolt shoulder pad and Warrior Player's Club Hitlyte shoulder pad) and three used models of the same shoulder pads with at least four seasons of use (Warrior MPG shoulder pad, STX Jolt shoulder pad and Warrior Player's Club Hitlyte shoulder pad) were tested. A drop mechanism was built that released a weighted ball on the thorax region of the shoulder pads to replicate game-like forces. Peak IF was measured with a motion analysis system (Peak Motus version 6.0) via a Bertec force plate (#K00606, Bertec Columbus, OH, USA).

ANALYSIS: To compare impact force between the pairs of new and used shoulder pads, three separate independent t-tests were run. A one-way ANOVA was run to determine if significant differences in IF exist among all six shoulder pads. Lastly, a one-way ANOVA was conducted to determine if price (as a latent variable) of shoulder pads differed by IF among the three new models.

RESULTS: The new models of shoulder pads reduced peak IF more effectively with the most expensive pads performing the best followed by the cheapest shoulder pad then the moderately priced shoulder pads.

CONCLUSION: New shoulder pads reduce peak IF better than older shoulder pads. Additionally, the cost of the shoulder pad may not be a true indicator of peak IF reduction.

ACKNOWLEDGEMENTS

I would like to thank the many professors and mentors that have helped me throughout this journey.

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CHAPTER 1

SUMMARY

Men's lacrosse is a fast-paced, free-flowing sport played on a field similar in size to a soccer field. Lacrosse has earned the nickname "the fastest game on two feet" because of the quickness and change of direction that occurs throughout a game. The game is growing at an extreme rate. In 2001 there were 253,931 youth players and by 2010 the number had grown to 624,593 (Vincent, Zdziarski, & Vincent, 2014). Lacrosse is unique from a medical provider point of view because the game is played with a combination of rapid movements, high ball velocity, and the use of sticks which results in a unique set of injury mechanisms and types (Hinton, 2005; Vincent et al., 2014). Many of these injuries occur in the shoulder and chest regions. Lacrosse shoulder pads are very thin pieces of equipment that may give the player a false sense of security (Putukian, Lincoln, & Crisco, 2014), which may explain why the upper extremity accounted for 26.2% of game injuries and 16.9% of practice injuries in men's lacrosse (Dick, Romani, Agel, Cae, & Marshall, 2007). Evidence exists showing that protective gear either makes no difference or encourages participants to play more dangerously, leading to higher injury rates (Yard & Comstock, 2006). Thus, it is plausible that better protective equipment could limit upper extremity injury rates in lacrosse players.

Currently, there have been no significant investigations on lacrosse shoulder pads. Given the growth in popularity of the sport, it is important that players are better informed on the limits of this mandatory piece of equipment (Vincent et al., 2014). There is a notable amount of injuries that occur to the upper extremity during games (Dick et al., 2007). Examining peak linear impact forces (IF) between old and new lacrosse shoulder pads can provide a better understanding to how these shoulder pads reduce peak IF differently.

Statement of the Problem

This study addressed the issue of new versus used lacrosse shoulder pads and their ability to properly reduce peak IF. The aim of this investigation was to compare new shoulder pads to the same (or similar) model of used shoulder pads that have had at least four seasons of play. Men's lacrosse has experienced rapid growth and therefore higher numbers of athletes are experiencing shoulder injuries. If men's lacrosse shoulder pads were improved to better protect the athlete, the injury rate may go down. Also, the lacrosse community needs to be better educated on the limits of the shoulder pad protection. Examining IF between new and used lacrosse shoulder pads can provide a better understanding to how these shoulder pads reduce peak IF differently, which could help to create standards for the testing of shoulder pads, and limit to the length of use which may decrease the injury rate.

Purpose of the Study

The purpose of this study was to examine the ability of new lacrosse shoulder pads to reduce peak IF and compare that to the ability of the same model of previously used shoulder pads. A secondary purpose of this study was to examine the cost-effectiveness of the shoulder pads based on the price and their ability to reduce peak IF.

Hypotheses

The dependent variables were years of use of the lacrosse shoulder pads and the cost. The hypotheses were: (1) New men's lacrosse shoulder pads would successfully reduce peak IF better than the same model of older shoulder pads; (2) More expensive pads would reduce peak IF better than cheaper pads.

Delimitations

The following were delimitations of the current study:

1. The researcher obtained and tested three new lacrosse shoulder pads (Warrior MPG 8.0 Lacrosse Shoulder Pad, STX Jolt Shoulder Pad and Warrior Player's Club Hitlyte Shoulder Pad). These shoulder pads were brand new, unused pads.
2. The researcher obtained and tested three older lacrosse shoulder pads (Warrior MPG Shoulder Pad, STX Jolt Shoulder Pad and Warrior Player's Club Shoulder Pad). These pads qualified for the study secondary to having at least 4 season of play.
3. The testing was completed in a controlled lab setting to measure the peak linear impact force.

Limitations

The following were limitations of the current study:

1. The shoulder pad impact tests did not occur in live game situations but were simulated in a lab.
2. Errors in the force plate testing equipment could have occurred from either manufacturing deficiencies or human error. Additionally, during the testing the force plate could not have recalibrated correctly in the amount of time given between tests.
3. The testing conducted utilized SUNY Cortland's only force plate.

Assumptions

The following were assumptions of the current study:

1. It was assumed that all shoulder pads that were tested had no manufacturer defects.
2. It was assumed that the older shoulder pads were used properly.

3. The three older shoulder pads were the same model as the three new shoulder pads.

Definition of Terms

For the purpose of the present study, the following terms were defined:

1. Game to practice injuries: the ratio of injuries compared between games and practices.
2. Contact injuries: An injury that occurs as a result of body to body contact.
3. Commotio cordis: “A life threatening injury that is a result of a blunt, non-penetrating blow to the chest, over the heart, at a critical time in the cardiac cycle which causes an often fatal arrhythmia” (Putukian et al., 2014, p. 338).

Significance of the Study

This study is valuable to the lacrosse community because it was the first study to compare peak IF reduction between new and used lacrosse shoulder pads. Additionally, this study compared the cost-effectiveness of the shoulder pads. It is in the nature of sports for injuries to occur. The theory behind adding padding to players is that it will help protect the athlete from injuries. However, in any contact sport, such as lacrosse, shoulder injuries are common (Headey, Brooks, & Kemp, 2007). There is a belief that protective equipment lowers injury rates. Unfortunately for the men’s lacrosse shoulder pad, the gear makes little to no difference in protecting athletes (Harris & Spears, 2010). One of the leading lacrosse equipment manufacturers, STX lacrosse, attaches a warning sticker to their equipment which states (2018) “This equipment is designed to protect lacrosse players from ordinary scrapes and bruises of the game, not from blows severe enough to break a bone or cause other serious injury.” This means that the pads are designed to do the bare minimum. Between 1980 and

2007, 23 sudden deaths have occurred in lacrosse due to injury (Putukian et al., 2014). There are a multitude of reasons why lacrosse would be a safer game with improved shoulder pads.

One issue of lacrosse shoulder pads is there are currently no standards. Phone calls to leading manufacturers revealed that their products are tested and that they are safe but this information is not released to the public. There are also no guidelines on how to properly maintain the equipment or for how long it should be used by an athlete. One significant, life-threatening injury that can occur in lacrosse is commotio cordis. Between 1980 and 2007, 23 sudden deaths have occurred in college and high school lacrosse. In 10 of these cases, the athlete sustained a blow to the chest prior to their collapse and had no evidence of underlying structural disease (Putukian et al., 2014). Current shoulder pads in men's lacrosse are not effective in preventing commotio cordis. Forty percent of sudden deaths caused by commotio cordis occur despite the use of commercially available sports equipment generally perceived as protective (Doerer, Haas, Estes, Link, & Maron, 2007).

CHAPTER 2

REVIEW OF LITERATURE

In the last twenty years, there has been worldwide growth in participation in lacrosse. Research has shown that lacrosse is the most rapidly growing team sport in the United States (McCulloch & Bach, 2007). The game is also growing in popularity at the international level with more and more countries joining the international federation of lacrosse every year. This federation is a governing body whose members have a strong lacrosse community and participate in an annual international tournament (Laduke, 2014). It is important for medical professionals to be familiar with the game and the unique injuries that have occurred during play, particularly because the mandatory shoulder pads offer little to no protection and there are no rules regarding their length of use.

Per the NCAA (2017) rule book, men's lacrosse requires participants to wear shoulder pads; however, these pads do not have any regulations or standards. Most NCAA Division III institutions do not provide this necessary piece of equipment to their athletes, and thus athletes are required to supply their own shoulder pads. Research has suggested that the shoulder pads should be redesigned and updated to better protect athletes (Dick, Romani, Agel, Cae, & Marshall, 2007). In the game of lacrosse, there has been a high rate of shoulder injuries and risk for a potentially life-threatening injury, commotio cordis (Madias, Maron, Supron, Estes, & Link, 2008; McCulloch & Bach, 2007). The lacrosse community needs to be properly educated in order to understand the existing limits to shoulder pads and how to best prevent commotio cordis. Lacrosse is a hybrid sport in the sense that it has physiological demands including endurance, speed, strength, agility, and sport-specific skills (Putukian et al., 2014). Like any other sport, lacrosse has inherent possibility of serious injury and there is

a high incidence of upper extremity injuries in men's lacrosse. Studies have shown that unlike the ice hockey shoulder pad, the lacrosse shoulder pad has not undergone the same evolution to better cover and protect the shoulder joint (Dick et al., 2007).

Background

The mandatory protective equipment required for men's lacrosse is a helmet, mouthpiece, gloves, elbow pads, and shoulder pads (Hinton, 2005). This equipment is standard for all levels of men's lacrosse, from youth players to Team USA professionals. Research indicates, however, that some of this equipment is ineffective in protecting the athlete (Doerer, Haas, Estes, Link & Maron, 2007). For instance, the lacrosse shoulder pad is much lighter, thinner and less bulky than the shoulder pads worn in other contact sports such as football and hockey (Dick et al., 2007). The lacrosse shoulder pad is a very small and seemingly inadequate piece of equipment, which could potentially lead players to a false sense of security (Thakar, Chandra, Pednekar, Kabalkin & Shani, 2012). There are no current standards or organizations which govern shoulder pads; however, the lacrosse helmet must meet the standards of the National Operating Committee on Standards for Athletic Equipment (NOCSAE) (Putukian et al., 2014). Having this committee in place ensures that lacrosse helmets must be updated and properly maintained in order to be used during play. As of 2014, the NOCSAE has developed standards that must be met by the lacrosse ball, however certification and maintenance standards are still lacking for lacrosse shoulder pads (NCAA, 2017). According to the NCAA (2017) rule book, "equipment manufacturers have undertaken the responsibility for the development of playing equipment" (p. 19). Equipment manufacturers are "urged" to use third party independent testing agencies to verify that their equipment is safe, but results from the testing are not often released to the public.

Since there are no current limitations for the amount of time lacrosse shoulder pads can be worn before mandatory replacement, players can (and, ultimately, will) continue to use the same pads for years. NCAA Division III lacrosse athletes participate in an average of 14 games and 57 practices per year, which results in approximately 56 games and 228 practices over the course of an athlete's four year career (Dick et al., 2007). This estimation does not consider out of season play that a lacrosse athlete may participate in such as summer tournaments. It also does not include the NCAA nontraditional fall season which adds additional wear time to the equipment.

It is a common fact that objects – like sports equipment – will deteriorate over time. Many studies have been conducted to analyze the effectiveness of the lacrosse helmet. One such study tested lacrosse helmets to determine the ability of the helmet to absorb attenuating forces (Caswell & Deivert, 2002). Results from the study indicated that impact forces increased for all four helmets with ten impacts, indicating that the helmets' ability to protect the players decreased as more impacts occurred (Caswell & Deivert, 2002). A similar study was conducted in which NOCSAE drop testing was used to evaluate three new and three used helmets. The used helmets all passed the NOCSAE testing requirements; however, mixed results were found in that it appears helmet use can degrade impact performance under some conditions but improve it in others (Bowman, Breedlove, Breedlove, Dodge & Nauman, 2015). Lacrosse helmets become less effective over time; it can be assumed that shoulder pads (which could be worn up to 284 times in a college career), would also become less effective over time. The unclear results of the two aforementioned studies indicate that lacrosse protective equipment such as helmets or shoulder pads requires further study and testing, and especially after the equipment has been used.

While American football and men's lacrosse are two different sports, they both require the use of shoulder pads because of body contact. Football shoulder pads are bulkier compared to lacrosse shoulder pads and provide more protection for a sport with more contact. There are standard rules to follow when sizing an athlete for football shoulder pads, however, there are very limited rules when sizing lacrosse shoulder pads. Football shoulder pad fitting must be verified by a certified athletic trainer or equipment manager. Lacrosse shoulder pads have fitting guides based on the athlete's size because there is currently no required verification for proper fit.

The design of lacrosse shoulder pads is different than football shoulder pads but they both have similar guidelines. Both pads in general are built to cover the sternum, clavicle, and scapula. Additionally, because the deltoid region of the shoulder is most often the location where contact is initiated, both football and lacrosse shoulder pads are designed to cover the deltoid muscle to protect from possible collisions from different angles (Casa et al., 2014). Surprisingly, many men's lacrosse shoulder pads are designed so that the deltoid protection flap can be removed via Velcro. The current trend in lacrosse shoulder pads is to have more parts of the pad removable to give the player a custom fit that offers greater mobility, but when pieces of the padding are removed, less protection is offered to the athlete.

Lacrosse shoulder pads are different from those used in other projectile sports like ice hockey. In hockey, the shoulder pads have been improved and updated over the past 30 years to accommodate frequently sustained injuries. Unfortunately, lacrosse shoulder pads have not been improved in the same manner (Dick et al., 2007). These pads are proving to not be effective in preventing many injuries – specifically, shoulder injuries such as clavicle

injuries, acromioclavicular joint sprains, glenohumeral dislocations, and subluxations (Harris & Spears, 2010). Further research is necessary to develop shoulder pads that are effective in men's lacrosse. One researcher believes that a redesign of the shoulder pads could include position-specific details, such as additional chest protection for defensemen who often face shooters and may be prone to serious injury if struck by a stick or the ball during a shot or pass (Dick et al., 2007).

Injuries

US Lacrosse is the national governing body for both men's and women's lacrosse. The organization reported that in 2001 there were 253,931 players, a number that nearly tripled to 624,593 by 2010 (Carter, Westerman, Lincoln, & Hunting, 2010). The NCAA has revealed that men's lacrosse participation in college went from 6,551 in 2001 to 10,903 in 2012. It is evident that lacrosse participation has been expanding at a quick rate across the United States (Vincent et al., 2014). With an increasing number of participants, it is natural that there has been a greater amount of injuries. Further, lacrosse athletes are almost four times more likely to sustain injuries in games compared to practices (12.58 versus 3.24 injuries per 1000 athlete exposures) (Dick et al., 2007; Hinton, 2005; Vincent, 2014).

Lacrosse is unique because it is an overhead collision sport (McCulloch & Bach, 2007). The main focus of the lacrosse shoulder pads is to prevent upper extremity injuries. However, research has found that the upper extremity accounted for 26.2% of game injuries and 16.9% of practice injuries in men's lacrosse (Dick et al., 2007). In a study conducted by Dick et al., (2007) the most frequent injuries that resulted in at least 10 consecutive days of restricted or total loss of participation were considered "severe injuries" (Dick et al., 2007). The second highest "severe" injury overall in games was acromioclavicular joint (AC)

injuries (7.3%) (Dick et al., 2007). It was found that game injury mechanisms are associated with player on player contact 45.9% of the time, followed by no apparent contact 26.5%, and contact with stick 12.9% (Dick et al., 2007).

Men's lacrosse players and their shoulder pads receive a multitude of different impacts during play. One particular impact players have received is body-to-body contact such as players checking one another; this part of the game typically leads to a high rate of injuries (Carter et al., 2010). Lacrosse shoulder pads also have to absorb forces produced from body contact, stick contact, helmet contact, and ball contact produced from falling onto the playing surface (Clark & Hoshizaki, 2016; Sherbondy, Hertel, & Sebastianelli 2006). Enhanced personal protective equipment and standards could limit the amount of injury rates (Carter et al., 2010).

Men's and women's lacrosse differ in that women's lacrosse is non-contact and there are no pads used. A study conducted on high school lacrosse players found that male high school players had a significantly higher amount of upper extremity injuries compared to high school girls (Hinton, 2005). It has also been shown that males have a higher rate of injury from player-player-contact compared to females. Findings from a three-year prospective study of high school lacrosse injuries showed males were more likely to sustain shoulder injuries than females (IRR = 2.38; 95% CI, 1.32-4.55) (Vincent et al., 2014). Research also indicates that males have experienced five times more serious shoulder injuries, requiring emergency care in the hospital, compared to females (Vincent et al., 2014).

The throwing mechanism in lacrosse has predisposed athletes to acute subluxations or dislocations of the shoulder. A subluxation or dislocation have occurred when a player is struck or falls to the ground while holding the stick overhead or at the player's side

(McCulloch & Bach, 2007). This position of shoulder internal or external rotation with force is the classic mechanism of injury for shoulder subluxations and dislocations. Men's lacrosse athletes are constantly in these positions during play. The proper throwing and shooting mechanisms causes both shoulders to be in positions of external and internal rotation.

In men's lacrosse, stick checking and body contact are permissible acts and create opportunities for injury. The AC joint of the shoulder is subject to a lot of stress in lacrosse and thus is often injured. It has been found that 28% of attackmen who attended a summer league incurred AC joint injuries such as sprains, dislocations, and clavicle fractures (Vincent et al., 2014). Lacrosse shoulder pads feature a non-cantilever design which allows the pad to rest directly on top of the shoulder (Prentice, 2014). This design allows the force of a blow to directly translate into the shoulder. Clavicle fractures and AC injuries have occurred from collisions with another player or fall onto the point of the shoulder (Hinton, 2005). Despite the use of shoulder pads, bony and ligamentous injuries occur around the shoulder girdle (McCulloch & Bach, 2007). New designs that offer better protection to the shoulder girdle could decrease the amount of acromioclavicular injuries.

Commotio Cordis

An injury that is unique to lacrosse and projectile sports in general is Comotio Cordis. According to Putukian et al. (2014) the definition of commotio cordis "is a life threatening injury that is a result of a blunt, non-penetrating blow to the chest, over the heart, at a critical time in the cardiac cycle which causes an often fatal arrhythmia" (Putukian et al., 2014, p. 338). Commotio cordis occurs when a blow to the chest happens at a vulnerable time in the cardiac cycle, ten to twenty milliseconds prior to the peak of the T wave. Research using an animal model has found that the blow often occurs over the cardiac silhouette at a velocity of

forty miles per hour, with ventricular fibrillation the most common arrhythmia (Madias et al., 2008). This is a life-threatening injury and is reported with increasing frequency (Madias et al., 2008). Unfortunately, these patients do not have any previous signs or symptoms of a heart condition prior to the trauma (Madias et al., 2008).

Comotio cordis is reported as the second leading cause of death in young athletes. Athletes around the age of 12-15 are at the greatest risk for commotio cordis because the chest is pliable and not fully developed (Putukian et al., 2014). The overall survival rate is 16% in the United States when no intervention occurs. When an automated external defibrillator (AED) is properly used in a timely manner, the survival rate is 41% (Putukian et al., 2014). Unfortunately, this injury still accounts for approximately 20% of sudden cardiac arrest deaths in young athletes (Casa et al., 2014).

Shoulder pads worn by goalies have been designed to reduce the risk of musculoskeletal injuries from ball shots by adding additional layers and a larger design. However, no standard for design or performance exists for shoulder pads in lacrosse (Putukian et al., 2014). Comotio cordis has occurred in midfielders as well as goalies wearing up-to-date shoulder pads (Vincent et al., 2014). According to Putukian et al. (2014) “between 1980 and 2007, 23 sudden deaths have occurred in college and high school lacrosse. In 10 of these cases, the athlete sustained a blow to the chest prior to their collapse and without evidence of underlying structural disease” (Putukian et al., 2014, p. 338).

Comotio cordis is a unique injury, which is a medical concern in lacrosse, because the lacrosse ball has acted as a projectile and has struck players (Putukian et al., 2014). Current shoulder pads in men’s lacrosse are not effective in preventing commotio cordis in reports of humans and clinical animal testing (Putukian et al., 2014). Research has found that

40% of sudden deaths in young athletes due to blunt cardiac injuries occur despite the use of commercially available shoulder pads (Madias et al., 2008). To prevent this tragic event, lacrosse shoulder pads could be regulated so that players have an understanding to the limits of their equipment.

Summary

The NCAA requires players to wear shoulder pads, but the NCAA does not provide regulations or standards in place to monitor these pads. Players can buy the inadequate shoulder pads, use Velcro to remove parts and not have them properly fitted like in other sports. In many cases players wear their shoulder pads for four years of play (Dick et al., 2007). The lacrosse shoulder pad does little to prevent shoulder and chest injuries such as shoulder dislocations and subluxations, labral tears, AC joint injuries and commotio cordis (McCulloch & Bach, 2007; Putukian et al., 2014). There are no standards or governing body for lacrosse shoulder pads. If a governing body was in place, it could help promote equipment standards to better protect athletes. As the number of lacrosse participants increases, improvements need to be made to the shoulder pads worn (McCulloch & Bach, 2007).

CHAPTER 3

RESEARCH BRIEF

To the best of our knowledge, there has been no known studies that have examined the integrity of used lacrosse shoulder pads. Research is needed concerning the appropriate length of use of shoulder pads. The purpose of this study was to examine the ability of new lacrosse shoulder pads to reduce peak IF and compare that to the ability of the same model of previously used shoulder pads. It also examined the abilities of the shoulder pads to reduce peak IF based on the price of the shoulder pads. The hypothesis of this study was that new men's lacrosse shoulder pads would successfully reduce peak IF better than the same model of older shoulder pads. It was also hypothesized that more expensive pads would better reduce peak IF.

Methods

The researcher examined peak IF of three new and three used lacrosse shoulder pads. The following sections describe testing instruments, testing procedures and data analysis.

Instruments. The study was conducted on six men's lacrosse shoulder pads. Three new lacrosse shoulder pads and three used shoulder pads were examined. The three commercially available, never before used lacrosse shoulder pads used were:

1. Model "1": Warrior MPG 8.0 Shoulder Pad
2. Model "3": STX Jolt Shoulder Pad
3. Model "5": Warrior Player's Club Hitlyte Shoulder Pad

The used shoulder pads that were used were the same models of the new shoulder pads that were tested, but have been used for at least four seasons of play. The used shoulder pads were donated to the researcher and were guaranteed to have been used for four seasons

of Division III college lacrosse play. The corresponding pads were referred to as models “2” (used version of Warrior MPG Shoulder Pad), “4” (used version of STX Jolt Shoulder Pad), and “6” (used version of Warrior Player’s Club Hitlyte Shoulder Pad). For the purpose of this study, the shoulder pads were organized into two separate groups: “new” and “old” shoulder pads. However, each individual shoulder pad was tested independently via drop test. The shoulder pads tested are represented in Figure 1.



Figure 1. *Shoulder Pads Tested*

Drop testing. For the drop testing, a mechanism was created that consisted of a platform with an electromagnet (Model WF-P25/25, Wuxue Wen Fang Electric Co. Ltd., China) that released a standard ball bearing weighing 600 grams. The drop mechanism is represented in Figure 2.

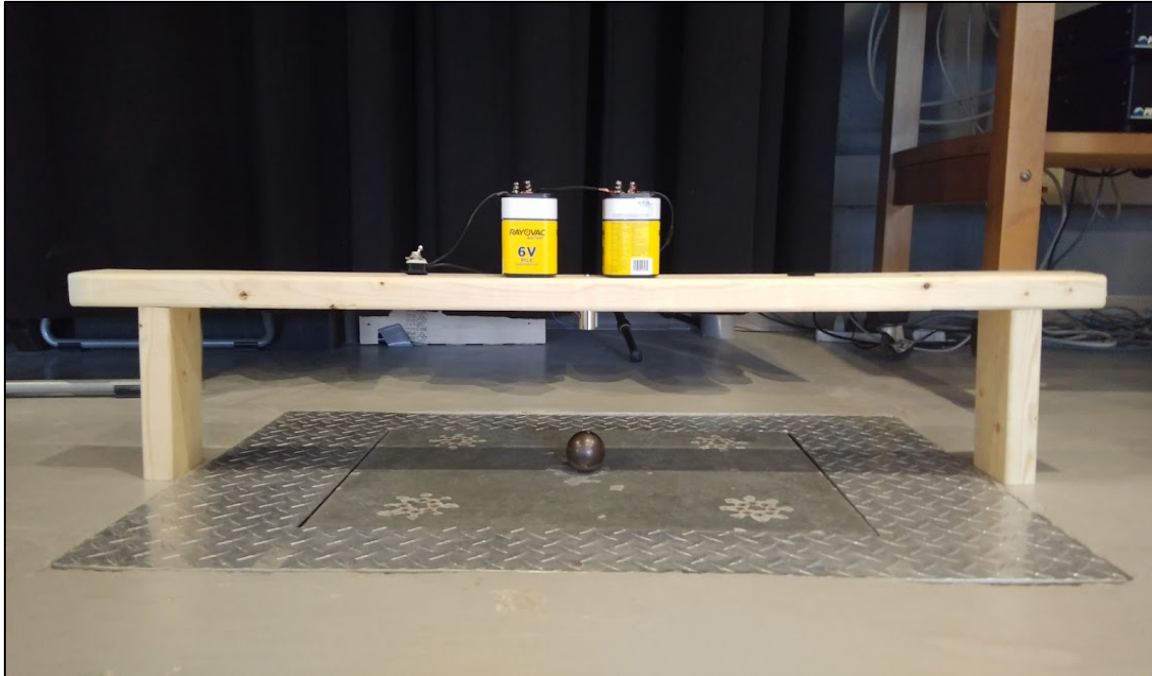


Figure 2. *Drop Mechanism*

The electromagnet was powered using two 6 Volt batteries (Model 944, Spectrum Brands Inc., Wisconsin, USA) and secured via bolt (M4-.70 x 50 Metric, The Hillman Group, INC, Ohio, USA). The ball bearing was released by a standard toggle switch. Electric connections were made with cable wire (16 Gauge Primary Wire, Southwire LLC, Georgia, USA). Five of the tested shoulder pads laid flat on the force plate. One model was secured by placing weighted plates (York Barbell USA, USA) on each corner of the shoulder pads to ensure that the pads would lie flat against the force plate. A Bertec force plate (#K00606, Bertec Columbus, OH, USA) was used. A motion analysis system (Peak Motus version 6.0) running on a personal computer captured the force transmitted through the shoulder pads to the force plate. The sampling rate was set to 2000Hz with a pre-trigger time set at 0.2 seconds. The total sampling time was one second. The trigger threshold was set at 0.1 volts.

Procedures. The drop testing was conducted by releasing a ball bearing from a height of 13.65 centimeters above the surface of the force plate. The ball bearing impacted on the center of each pair of shoulder pads. The ball bearing was dropped at a height of 13.65 centimeters to simulate body contact collision forces of roughly 1000 newtons (Harris & Spears, 2010). The first test that was conducted was on a naked force plate to ensure correct testing calibrations. The ball bearing was then dropped a total of 20 additional times to ensure testing accuracy. After successful calibration, the first pair of shoulder pads was placed on the force plate in an open position so that only the front aspect of the shoulder pads was exposed. The drop mechanism with shoulder pads is represented in Figure 3.



Figure 3. *Drop Mechanism with Shoulder Pad*

The ball bearing was then dropped one hundred times in the sternum region of the shoulder pads and the peak impact force was recorded for each drop. The average IF across the one hundred trials was calculated and retained for analyses. Identical testing procedures

were used on the two remaining new shoulder pads (3 and 5) and the used shoulder pads (2, 4, and 6).

Data analysis. Peak IF obtained from each of the six shoulder pads was used as the primary dependent variable. Means and standard deviations of IF from each of the six pads are reported along with mean cost of each of the new pads. To compare IF between the pairs of new and used shoulder pad models, a series of independent *t*-tests were conducted: 1 and 2, 3 and 4, and 5 and 6. A one-way ANOVA was conducted to determine if significant differences in IF exist among all shoulder pads (1, 2, 3, 4, 5, and 6). Lastly, a one-way ANOVA was conducted to determine if the new shoulder pads differed in terms of price. All analyses were conducted with SPSS version 23.

Results

Means and standard deviations of the six shoulder pads' mean IF in newtons and cost are presented in Table 1.

Table 1

Descriptive Statistics of Shoulder Pads

	Mean (N)	Std. Deviation (N)	Cost (\$)
Model 1	148.06	5.35	29.95
Model 2	172.36	3.34	-
Model 3	155.74	5.54	65.99
Model 4	179.49	4.49	-
Model 5	73.90	1.81	119.98
Model 6	190.29	2.82	-

Comparison of new and used shoulder pads. A series of independent samples t -tests were run to compare IF between the various sets of new and used shoulder pads. There was a statistically significant difference in mean IF between shoulder pad Model 1 and Model 2, $t(198) = -38.467$, $p < .001$. Shoulder pad Model 1 significantly reduced peak IF more than Model 2 ($m = 148.06$ N versus $m = 172.36$ N, respectively). Mean IF is represented in Table 2.

Table 2

Comparison of IF between Model 1 and Model 2

	Mean (N)	Std. Deviation (N)	Std. Error Mean (N)
Model 1	148.06	5.35	.53
Model 2	172.36	3.34	.33

An independent t -test revealed a statistically significant difference in mean IF between shoulder pad Model 3 and Model 4, $t(198) = -33.26$, $p < .001$. Shoulder pad Model 3 significantly reduced peak IF more than Model 4 ($m = 155.7$ N versus $m = 179.49$ N, respectively). Mean IF is represented in Table 3.

Table 3

Comparison of IF between Model 3 and Model 4

	Mean (N)	Std. Deviation (N)	Std. Error Mean (N)
Model 3	155.74	5.54	.55
Model 4	179.49	4.49	.44

There was a statistically significant difference in mean IF between shoulder pad Model 5 and Model 6, $t(198) = -346.72, p < .001$. Shoulder pad Model 5 significantly reduced peak IF more than Model 6 ($m = 73.90$ N versus $m = 190.29$ N, respectively). Mean IF is represented in Table 4.

Table 4

Comparison of IF between Model 5 and Model 6

	Mean (N)	Std. Deviation (N)	Std. Error Mean (N)
Model 5	73.90	1.81	.18
Model 6	190.29	2.82	.28

Comparison of all shoulder pads. The following statistical analysis examined if there were significant difference in IF among all shoulder pad models. A one-way ANOVA was conducted to compare the effects of IF impact force on shoulder pad model. There was not homogeneity of variances, as assessed by Levene's test for equality of variances ($p < .001$). IF was statistically significantly different among all shoulder pads, $F(5, 594) = 10285.502, p < .001, \omega^2 = .998$. Post-hoc analyses revealed significant differences among all possible combinations of shoulder pads (presentation of results of all pairwise comparisons follows). Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 2 ($m = 172.36$ N, $SD = 3.347$ N). Between these two models, there was a statistically significant difference of -24.300 newtons, 95% CI [-25.97, -22.63] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 3 ($m = 155.74$ N, $SD = 5.548$ N). Between these two models, there was a statistically significant difference of -7.680 newtons, 95% CI [-9.35,

-6.01] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 4 ($m = 179.49$ N, $SD = 4.494$ N). Between these two models, there was a statistically significant difference of -31.430 newtons, 95% CI [-33.10, -29.76] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 5 ($m = 73.90$ N, $SD = 1.812$ N). Between these two models, there was a statistically significant difference of 74.160 newtons, 95% CI [72.49, 75.83] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 6 ($m = 190.29$ N, $SD = 2.826$ N). Between these two models, there was a statistically significant difference of -42.230 newtons, 95% CI [-42.230, -40.56] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 2 ($m = 172.36$ N, $SD = 3.347$ N) and Model 3 ($m = 155.74$ N, $SD = 5.548$ N). Between these two models, there was a statistically significant difference of 16.620 newtons, 95% CI [14.95, 18.29] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 2 ($m = 172.36$ N, $SD = 3.347$ N) and Model 4 ($m = 179.49$ N, $SD = 4.494$ N). Between these two models, there was a statistically significant difference of -7.130 newtons, 95% CI [-8.80, -5.46] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 2 ($m = 172.36$ N, $SD = 3.347$ N) and Model 5 ($m = 73.90$ N, $SD = 1.812$ N). Between these two models, there was a statistically significant difference of 98.460 newtons, 95% CI [96.79, 100.13] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 2 ($m = 172.36$ N, $SD = 3.347$ N) and Model 6 ($m = 190.29$ N, $SD = 2.286$ N). Between these two models, there was a statistically significant difference of -17.930 newtons, 95% CI [19.60, -16.26] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 3 ($m = 155.74$ N,

SD = 5.548 N) and Model 4 ($m = 179.49$ N, SD = 4.494 N). Between these two models, there was a statistically significant difference of -23.750 newtons, 95% CI [-25.42, -22.08] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 3 ($m = 155.74$ N, SD = 5.548 N) and Model 5 ($m = 73.90$ N, SD = 1.812 N). Between these two models, there was a statistically significant difference of 81.840 newtons, 95% CI [80.17, 83.51] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 3 ($m = 155.74$ N, SD = 5.548 N) and Model 6 ($m = 190.29$ N, SD = 2.286 N). Between these two models, there was a statistically significant difference of -34.550 newtons, 95% CI [-36.22, -32.88] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 4 ($m = 179.49$ N, SD = 4.494 N) and Model 5 ($m = 73.90$ N, SD = 1.812 N). Between these two models, there was a statistically significant difference of 105.590 newtons, 95% CI [103.92, 107.26] $p < .001$. Tukey post-hoc analysis indicated significant differences between Model 4 ($m = 179.49$ N, SD = 4.494 N) and Model 6 ($m = 190.29$ N, SD = 2.286 N). Between these two models, there was a statistically significant difference of -10.800 newtons, 95% CI [-12.47, -9.13] $p = .000$. Lastly, a Tukey post-hoc analysis indicated significant differences between Model 5 ($m = 73.90$ N, SD = 1.182 N) and Model 6 ($m = 190.29$ N, SD = 2.286 N). Between these two models, there was a statistically significant difference of -116.390 newtons, 95% CI [-18.06, -114.72] $p < .001$. This statistical analysis revealed significant differences among all possible combinations of shoulder pads. In order from best to worst absorption of IF, Model 5 performed the best with an IF of 73.90 newtons, followed by Model 1 with 148.06 newtons, then Model 3 with 155.74 newtons, Model 2 with 172.36 newtons, Model 4 with 179.36 newtons and lastly Model 6 with 190.29 newtons.

Cost comparison of new shoulder pads. The following statistical analysis was run to determine if there were significant differences in IF between the new lacrosse shoulder pads based on cost. Model 1 cost \$29.95, Model 3 cost \$65.99 and Model 5 cost \$119.98. A one-way between-subjects ANOVA was conducted to compare the three new shoulder pads (Models 1, 3, and 5) by price. There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .142$). IF was statistically significantly different among the tested shoulder pads, $F(2,297) = 3237.917$, $p < .0005$, $\omega^2 = .955$. Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 3 ($m = 155.74$ N, $SD = 5.548$ N). Between these two models, there was a statistically significant difference of -7.680 newtons, 95% CI $[-10.29, -5.07]$ $p < .001$. A Tukey post-hoc analysis indicated significant differences between Model 1 ($m = 148.06$ N, $SD = 5.358$ N) and Model 5 ($m = 75.02$ N, $SD = 11.155$ N). Between these two models, there was a statistically significant difference of 73.040 newtons, 95% CI $[70.43, 75.65]$ $p < .001$. Lastly, Tukey post-hoc analysis indicated significant differences between Model 3 ($m = 155.74$ N, $SD = 5.548$ N) and Model 5 ($m = 75.02$ N, $SD = 11.155$ N). Between these two models, there was a statistically significant difference of 80.720 newtons, 95% CI $[78.11, 83.33]$ $p < .001$. This statistical analysis revealed significant differences among all possible combinations of new shoulder pads based on their cost. In order from best to worst absorption of IF based on cost, Model 5 (\$119.98) performed the best with an IF of 73.90 newtons, followed by Model 1 (\$29.95) with an IF of 148.06 newtons, and Model 3 (\$65.99) with an IF of 155.74 newtons.

Discussion

The findings indicated that new shoulder pads reduced peak IF better than a similar model of shoulder pads that had been used for at least four seasons of play. In general, more expensive shoulder pads reduced peak IF better than less expensive shoulder pads.

A comparison of the new and used shoulder pads indicated that new shoulder pads reduced peak IF better than used shoulder pads of the same (or similar) model, which supported the first hypothesis. Lacrosse shoulder pads have no standards for limitation of use so a senior college lacrosse player could be wearing the same pads for four years, or approximately 56 games and 228 practices of wear-time (Dick et al., 2007). Other studies have indirectly supported these findings. One such study tested lacrosse helmets to determine the ability of the helmet to absorb attenuating forces and found that impact forces increased for all four helmets with ten impacts, indicating that the helmets' ability to protect the players decreased as more impacts occurred (Caswell & Deivert, 2002). A similar study was conducted in which drop testing was used to evaluate three new and three used helmets. The results suggested that lacrosse helmets become less effective over time; it can be assumed that shoulder pads would also become less effective over time (Bowman, Breedlove, Breedlove, Dodge & Nauman, 2015). The lack of quality protective shoulder pads can help to explain the injury rate to the upper extremity in lacrosse, which accounted for 26.2% of game injuries and 16.9% of practice injuries (Dick et al., 2007). Enhanced personal protective equipment and standards could limit the amount of injury rates for other lacrosse injuries such as shoulder subluxations and dislocations (Carter et al., 2010). Lastly, better shoulder pads could help to protect players from the potentially fatal commotio cordis injury.

A comparison of all six shoulder pad models indicated that some models performed better in terms of reducing peak IF than others. All newer models of pads significantly

outperformed all used models in reducing peak IF. The range of IF absorption between the best-performing model and the worst-performing model was 116.39 newtons, indicating that different models of shoulder pads can have a vastly different IF absorption ability. This difference in IF is significant because it indicates that some shoulder pads do a much better job in terms of peak IF reduction compared to other shoulder pads. A similar study conducted drop testing on rugby shoulder pads found that each model tested had vastly different IF rates no matter the height or the object being dropped (Harris & Spears, 2010). Having standards in place to regulate absorption capabilities could help the consumer in purchasing the shoulder pads, and provide justification for limits-of-use for older shoulder pads. Additionally, better force absorption likely leads to a decreased chance of injury.

The cost analysis indicated mixed results. Not surprisingly, the most expensive pad (Model 5; \$119.98) performed best but was followed by the least expensive pad (Model 1; \$29.95). The shoulder pad with the mid-range cost (Model 3; \$65.99) reduced peak IF the least among all three new pads. This finding partially supports the hypothesis that the cost of the pad would impact the ability of the pad to reduce force. The relationship between cost and peak IF reduction in the shoulder pads tested indicates that the cost compared to the value is not a true indicator of the effectiveness of the shoulder pads. Because there are no regulations/standards for collegiate lacrosse shoulder pads, many consumers might consider the price of the pad to be of greater importance than the safety the pad may or may not provide. The findings indicated that by selecting Model 1 over Model 3, a consumer would save \$36.04 and gain 7.68 newtons of peak IF reduction. However, if the consumer were to purchase the most costly shoulder pads, Model 5 (\$119.98), they are essentially getting double the protection as Model 5 had an average peak IF reduction of 73.90 newtons

compared to Model 1's peak IF reduction of 148.06 newtons. The findings indicate that the best value for the cost would be the most costly shoulder pads, Model 5, because they reduce peak IF significantly better than the other two new models.

Conclusion

Findings from this study indicate that newer, more expensive shoulder pads reduce peak IF better than older, cheaper shoulder pads. While the most expensive pad performed the best, the least expensive pad outperformed the moderately-priced pad. This indicates that cost is not a true representation of a shoulder pad's peak IF reduction abilities.

The study was not without limitations. The testing was conducted in a controlled laboratory setting and not in a game or practice scenario. The shoulder pads were tested on a force plate rather than on human subjects. While the "used" pads were intended to be the exact version of their respective newer pad, the models of each of the new pads have changed slightly over the course of four years, so the older pads may have been slightly different than their newer model. Another limitation is that the drop height and velocity was held constant throughout the testing. Other drop testing studies have changed the height, velocity, and projected object (Harris & Spears, 2010), which could better simulate lacrosse competition. Lastly, only two of the major manufacturers of lacrosse shoulder pads were tested. There are several other companies that make lacrosse shoulder pads that were not tested in this study.

Strengths of the study included the drop mechanism that was created, which allowed for consistent and repeatable drop testing. The similarity between the new and used models was also a strength of the study. Lastly, to the best of our knowledge, this is the first study to examine IF of various models of lacrosse shoulder pads.

Future research should examine the length of effectiveness of lacrosse shoulder pads. While the NCAA recommends this testing, it does not require it (“NCAA,” 2017). Additionally, a greater number of shoulder pads could be tested. These shoulder pads should also be tested by having different objects dropped onto them at different heights. Also, different objects could be dropped on the shoulder pads to better represent body contact. Sports medicine specialists see a variety of injuries, and in lacrosse, injuries to the shoulder region are highly common (Heady et al., 2007). Many injuries involving the acromioclavicular joint, glenohumeral joint and the life-threatening injury of commotio cordis (Vincent et al., 2014) may be preventable with pads that properly reduce peak IF. Athletic trainers, athletes, coaches, parents, officials, and players should be aware of the potential for injury that can occur when standard shoulder pads do not provide appropriate protection

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