

Football Shoulder Pad Design and Its Effect on Head Kinematics in Shoulder-to-Helmet Impacts

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ACADEMIC ABSTRACT

Shoulder-to-helmet (STH) impacts have been shown to cause approximately twenty percent of concussions in football [1, 2], yet little research has investigated shoulder pad design and STH impacts. While shoulder pads are designed to protect the player wearing them, they have the potential to better protect the struck player in STH collisions. This study aimed to characterize STH impacts and identify the effect of shoulder pad stiffness on the struck head kinematics. Additional padding was added to a shoulder pad as means to reduce the overall stiffness of the system, and an unmodified shoulder pad acted as the control. Participants performed a series of impact tests with two shoulder pad variations to identify if additional padding in the shoulder pads could reduce head kinematics. Participants struck a helmeted Hybrid III dummy with a National Operating Committee on Standards for Athletic Equipment (NOCSAE) on the side, replicating a lateral STH impact. Linear and rotational kinematics of the struck head were recorded for each impact, and impact speed was derived from high-speed video. Peak kinematics were compared between shoulder pad configurations to identify differences in pad performance. Impact response corridors were developed from this study that could be used to inform future controlled laboratory test setups that replicate STH impacts. A controlled test setup would allow for future testing at higher impacts speeds to evaluate concussive level impacts. Overall, this study aimed to identify if shoulder pad design can affect the struck head kinematics in STH impacts, which would open a new avenue of player safety research and development.

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GENERAL AUDIENCE ABSTRACT

Shoulder-to-helmet (STH) impacts have been shown to cause approximately twenty percent of concussions in football [1, 2], yet little research has investigated shoulder pad design and STH impacts. While shoulder pads are designed to protect the player wearing them, they have the potential to better protect the struck player in STH collisions. This study aimed to characterize STH impacts and identify the effect of shoulder pad stiffness on the struck head kinematics. Participants performed a series of impact tests with two shoulder pad variations to identify if additional padding in the shoulder pads could reduce head kinematics. Participants struck the side of a crash test dummy head with their shoulder to replicate a STH impact. Linear and rotational kinematics were recorded for each impact, and impact speed was derived from high-speed video. Values that are used to quantify head injury were compared between shoulder pad configurations to identify differences in pad performance. This study defined impact response corridors that could be used to inform future controlled lab test setups that replicate STH impacts. A controlled test setup would allow for future testing at higher impacts speeds to evaluate concussive level impacts. Overall, this study aimed to identify if shoulder pad design can affect the struck head kinematics in STH impacts, which would open a new avenue of player safety research and development.

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CHAPTER 1

INTRODUCTION

Football is one of the most popular sports in the United States. From youth leagues to the National Football League (NFL), football is known to be a very physical and aggressive sport. Since the introduction of the game in 1869, protective equipment has developed significantly, with a large focus on helmet design in response to the identification of concussion risk in the sport [3-7]. With the implementation of advanced padding material and material science technology, shoulder pads have largely evolved from their initial construction of leather and wool [8]. Over the years, shoulder pads have been fine tuned to reduce weight and size, allowing players to have more mobility and speed. Although the construction of the pads has changed over the years, the overall design of the shoulder pads has stayed similar.

There are two main types of shoulder pads: a flat pad design and a cantilever pad design [9]. The cantilever pads have a cantilever strap that goes across the shoulder arch which helps disperse the load. The cantilever pads are designed for interior players (lineman, linebackers, etc.). The flat pads have a more discrete profile that uses a compact pad design to protect the player while not sacrificing mobility. The flat pads are very popular among skilled position players (wide receivers, cornerbacks, running backs, etc.) and are starting to be worn by all positions as speed and mobility are crucial in all aspects of the game.

While shoulder pads are designed to protect the player wearing them, they may have potential to serve an additional role in player safety. Recent retrospective surveillance studies have found that shoulder-to-helmet (STH) impacts accounted for approximately 20% of concussive impacts

evaluated from multiple NFL seasons [1, 2]. Considering this relatively large potential for impact on player safety, the objective of this study was to evaluate the capability of shoulder pad design to reduce head kinematics for STH impacts. If modifications to the shoulder pad are proven to reduce head kinematics, a whole new area of research could be explored in shoulder pad design and concussion risk mitigation, further improving player safety through protective equipment.

The implementation of additional foam material within the interior workings of the shoulder pad was characterized as a reduced stiffness for the overall shoulder pad system. Ultimately, the additional padding in the shoulder pads acted as a modulator for the system, which we expected to help reduce head kinematics for the struck head.

CHAPTER 2

Football Shoulder Pad Design and Its Effect on Head Kinematics in Shoulder-to-Helmet Impacts

ABSTRACT

Shoulder-to-helmet (STH) impacts have been shown to cause approximately twenty percent of concussions in football [1, 2], yet little research has investigated shoulder pad design and STH impacts. This study aimed to characterize STH impacts and identify the effect of shoulder pad stiffness on the struck head kinematics. Additional padding was added to a shoulder pad as means to reduce the overall stiffness of the system, and was then compared to an unmodified control shoulder pad. Participants performed a series of impact tests with two shoulder pad variations to identify if additional padding in the shoulder pads could reduce head kinematics. Participants struck a helmeted Hybrid III dummy with a NOCSAE head with a lateral STH impact. Linear and rotational kinematics were recorded for each impact, and impact speed was derived from high-speed video. Peak kinematics were compared between shoulder pad configurations and impact response corridors were developed. The study found the modified shoulder pad reduced peak linear acceleration by 31% ($\Delta\mu = -9.13 \text{ g's } (-\infty, -7.25), (p=4.10\text{e-}08)$), rotational acceleration by 28% ($\Delta\mu = -565 \text{ rad/s}^2 (-\infty, -435), (p=2.10\text{e-}07)$), peak rotational velocity by 10% ($\Delta\mu = -2.42 \text{ rad/s } (-\infty, -1.54), (p=6.9\text{e-}05)$), and increased impact duration by 40% ($\Delta\mu = 9.96 \text{ ms } (8.06, \infty), (p=1.142\text{e-}08)$). The impact response corridors can be used to establish a controlled lab test setup that replicates STH impacts. Although the overall impact severity of the observed impacts was below concussive levels, the data gave promise to the role of shoulder pad design in reducing concussion risk.

INTRODUCTION

Concussions are a well-known issue in football and have drawn a large concern for player safety across all levels and age groups. Increased awareness of players' exposure to head impacts and the rising issue of concussions in the sport have amplified the importance of player safety over the past two decades [2, 6, 7, 10-13]. As a result, extensive research on head contact and helmet design has pushed helmet companies to develop safer products [3-5, 14]. Studies have shown that shoulder impacts to the head are one of the top-three most common mechanisms of concussions in football [1, 2]. There currently is no published research on football shoulder pads or shoulder-to-helmet (STH) impacts, and there are no publicly-made standards or certifications for shoulder pad design.

Two separate studies investigated concussive impacts during National Football League (NFL) seasons via retrospective video surveillance, defining the mechanism of injury, impact location, and impact speed. The first study reviewed seasons from 1996 to 2001 and found 61% of the concussive impacts to be helmet-to-helmet (HTH) contact and 16% to be shoulder-to-helmet (STH) impacts [2]. Since 2002, numerous rule changes in the sport have discouraged helmet-to-helmet contact [15], which in return causes players to lead contact with their shoulder or other parts of their body. The second study reviewed seasons from 2015 to 2017 and found only 36% of concussive impacts were from HTH, while impacts that involved the shoulder accounted for 22% (17% pure STH, 5% shoulder and body to helmet) [1]. The decrease in HTH impacts between the two studies could infer that STH impacts are becoming more prevalent and should be a strong focus area for player safety research.

There are no prior studies on shoulder pads regarding head impact response in football, but studies have looked at the effects of shoulder pad design on head injury in hockey. Virani et al.

conducted a test series involving 15 human subjects with varying hockey experience [16]. They struck an instrumented kickboxing dummy with different shoulder pads to identify the effects of hockey shoulder pads on head impact response. Their findings stated that the additional padding on the exterior shoulder pad crest decreased the average peak linear acceleration by 25% and the average peak rotational velocity by 12.4% compared to the unmodified shoulder pad. The study suggested shoulder pads might have a role in reducing head injury in sports. Kendall et al. also investigated the effect of shoulder pad design on head impact response in hockey, focusing on the material at the pad's contact point [17]. The study applied padding variations to the cap of a linear impactor, replicating a shoulder that struck an instrumented Hybrid III head, measuring linear and rotational acceleration. The study found differences in head impact response between pad variations, yet pad types were not consistent in performance across all impact parameters or impact speeds. They noted that the differences in performance between the two impact velocities for peak rotational acceleration could be due to the material bottoming out and creating a coupling effect. The study provided evidence that shoulder pad material and design can be tuned to reduce head acceleration. Both studies suggested shoulder pads can reduce head kinematics in hockey impacts, yet it's unknown how translatable the findings are to football shoulder pads and impacts.

Football shoulder pads are designed to spread the initial load, absorb, and then redirect the energy from the impact. In the STH impacts, shoulder pads provide an opportunity to mitigate the amount of energy delivered to the head and elongate the energy transfer process. Additional padding inside the shoulder pad reduced the overall stiffness of the modulator system. This study aimed to identify if additional padding in the shoulder pad could reduce the struck head impact response and develop impact response corridors that define the impact response of the struck

head in an STH impact. We hypothesized that additional padding in the shoulder pads will reduce the struck head kinematics and the overall impact severity.

METHODS

This study had participants strike the helmeted head of a dummy with different shoulder pad configurations to characterize and compare head kinematics in STH impacts. Twenty participants with varsity-level football experience were recruited for this study (IRB#21-526). Each participant conducted six impacts, three per shoulder pad variation, resulting in 120 total impacts. The majority of concussive STH impacts in the NFL data were delivered to the side of the helmet [1]. Our test setup replicated a side impact where participants used the top flap of the shoulder pad to strike the upper side of the helmeted head (Figure 1). Participants had a 5-meter perpendicular runway to gain speed before striking the dummy and were instructed to hit the dummy as hard as they felt comfortable. Participants were also given practice trials to get comfortable with the impact before data collection trials.



Figure 1: Video frames from a control pad test show the participant's approach, impact, and follow-through for the STH impact. The participant gained speed before striking the side of the helmet with the top flap of the shoulder pad. Participants were told to hit the helmet as hard as they felt comfortable. Markers on the top of the helmet and shoulder pad were used to track impact velocity in video analysis software.

Multiple kinematic measures are evaluated to understand head impact severity. The accelerative loading of the head causes stress and strain responses which are considered primary brain injury

mechanisms [18-22]. Linear and rotational head kinematics are correlated with the brain's tissue-level response and are often used to estimate concussion risk [10, 11, 23-26]. A Hybrid III 50th percentile male test dummy equipped with an instrumented NOCSAE head containing three linear accelerometers (Endevco 7264b-2000, PCB Piezotronics, Depew, NY) and three angular rate sensors (ARS3 PRO, $\pm 18k$ deg/s, Diversified Technical Systems, Seal Beach, CA) located at the head's center of gravity was used for data collection. Studies have shown the capability of a NOCSAE head with the three accelerometer, three angular rate sensor setup to be an appropriate alternative to the Hybrid III head with the nine-accelerometer array when evaluating helmeted head impacts [27-29]. Two high-speed cameras (FDR-AX700, Sony, New York City, NY) were used to record the impacts at 960 frames per second. Data from the top-view camera was used to compute the speed at which the participants struck the helmet in TRACKER software. Data from the side-view camera was used to analyze the area of the shoulder pad that struck the helmet and to verify the contact points between the shoulder pad and helmet. Accelerometers and angular rate sensors were sampled at 20,000 Hz and captured during a 150-millisecond window. The data acquisition system (SLICE PRO, Diversified Technical Systems, Seal Beach, CA) was triggered by a linear acceleration greater than five g's in the positive Y direction according to the SAE J211 coordinate system.

The test dummy was suspended at a 40-degree angle, allowing the participants to strike the head with their shoulder without any obstruction or interference with the rest of the dummy. Straps on each hip anchored the dummy and provided a consistent resting position while not limiting the initial kinematic response from the impact. The height of the dummy was adjusted based on the participants' shoulder height, with the dummy's helmet lining up 15 cm below their shoulder. A

marker was placed on the upper left side of the helmet as a target for the participants to strike.

Figure 2 shows the setup of the test dummy.



Figure 2: Side view of instrumented test dummy used for testing. A Hybrid III 50th percentile male test dummy equipped with a NOCSAE head was suspended from a swivel crane and was anchored at the hip with ratchet straps. A marker on the upper side of the helmet acted as a target for the participant to strike. The height of the dummy was adjustable to accommodate for the varying height of participants.

This study used two shoulder pads: an unmodified Douglas SW24 flat pad (Douglas, Houston, TX) and a modified Douglas SW24 flat pad with additional vinyl nitrate padding on the striking shoulder. Participants and the test dummy were equipped with a Riddell Speedflex Helmet (Riddell, Rosemont, IL). Video analysis of preliminary impacts was evaluated to determine the primary locations for additional padding. From this, Vinyl Nitrate 600 (DER-TEX, Saco, ME), a common closed-cell foam padding, was added to the top flap (1.27 cm), the interior arch (1.27

cm), and the shoulder resting point (2.54 cm). A depiction of the two shoulder pad models is shown in Figure 3.



Figure 3: Two identical Douglas SW24 flat shoulder pads were used to compare the effect of three additional layers of vinyl nitrate 600, a common closed-cell foam padding, which was inserted at the following locations: A) underneath the top flap (1.27 cm), B) below the interior arch (1.27 cm), and C) the shoulder resting point (2.54 cm).

Video was used to categorize the contact location on the shoulder pad for each impact. While participants were asked to strike the head with the top flap of the shoulder pad, the striking technique varied. Impacts that occurred on the chest and bottom flap were removed from the analysis since no modifications were made to those portions of the pads. Out of the 120 total impacts, nine impacts were removed. Both the chest and bottom flap locations produced impact

response characteristics that were notably different than impacts that involved the top flap.

Figure 4 shows how the impact locations of the shoulder pad were defined.

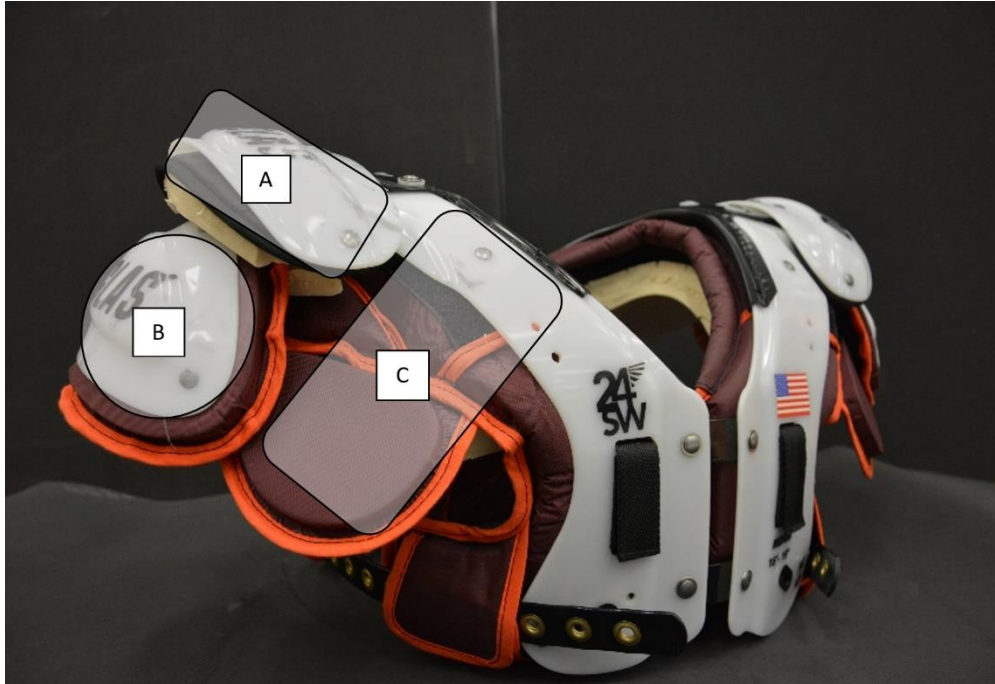


Figure 4: Diagram of the regions of the shoulder pads where impacts during testing occurred.

The study was designed for impacts to occur at A (top flap) so that the modifications would be engaged in impacts. Impacts in regions B (bottom flap) and C (chest), nine impacts in total, were removed from the study.

After data collection, a low pass Butterworth four-pole phaseless filter was applied to the data according to the SAE J211 standard, with a channel frequency class of 1000 for linear acceleration and 180 for angular rates. Rotational velocity was differentiated to compute rotational acceleration. Data from each impact were summarized by computing peak linear acceleration (PLA), peak rotational acceleration (PRA), peak rotational velocity (PRV), and duration. The Y-acceleration was evaluated to define the start and end time of the impact since

it was the primary response signal. The start was defined as the first time the acceleration pulse was 20% of the peak value, and the end time was defined as the first time after the peak that the acceleration pulse fell below 20% the peak value.

Kinematic values from the repeated trials for each participant and pad variation were averaged. Paired t-tests were conducted, with a statistical significance level of $\alpha=0.05$, to compare the modified shoulder pad to the control. We used one-sided t-tests since we expected there to be an increase in impact duration and a reduction in PLA, PRA, and PRV.

Impact response corridors for resultant head kinematics were constructed using a modified version of the Maltese method to understand the response characteristics of both pad models [30]. The first step in creating the corridors was to time-align the signals to reduce the effect of time variance. The impact duration start and end times were used to identify the region of interest for assessing signal variance. Each signal was compared to a reference signal, and the variance between the two signals within the characteristic range was computed and averaged. Then the signal was time-shifted back until the peak reached the reference start time, and forward until the peak reached the reference end time, to identify the time shift that resulted in the lowest variance. Once the time shift for a test was identified, all response curves of that test were shifted accordingly. The variances were averaged rather than summed to eliminate the possibility of the signal overlap size influencing the outcome. After the signals were aligned, the mean response and standard deviation at each time point were calculated. The corridors highlighted the average response curve and were bounded by one standard deviation. The corridors were developed so the STH impacts recorded in this study from human participants could be replicated in future laboratory-controlled impacts. Once a controlled experimental setup

is established, the impact speed could be increased to identify the impact response for higher severity impacts.

RESULTS

The modified shoulder pad reduced all measured head kinematics and extended the impact duration compared to the control pad. The additional padding produced a 31% reduction in the peak linear acceleration ($\Delta\mu = -9.13 \text{ g's } (-\infty, -7.25)$, ($p=4.10\text{e-}08$)), a 28% reduction in peak rotational acceleration ($\Delta\mu = -565 \text{ rad/s}^2 (-\infty, -435)$, ($p=2.10\text{e-}07$)), a 10% reduction in peak rotational velocity ($\Delta\mu = -2.42 \text{ rad/s } (-\infty, -1.54)$, ($p=6.9\text{e-}05$)), and a 40% increase in impact duration ($\Delta\mu = 9.96 \text{ ms } (8.06, \infty)$, ($p=1.142\text{e-}08$)). Impact speed was consistent throughout testing and was not dependent on the pad variation ($\Delta\mu = 0.075 \text{ m/s } (-0.16, 0.31)$, $p=0.502$). The average impact speed was $5.8 \pm 0.3 \text{ m/s}$. Table 1 shows the head impact parameters for both pad variations and their respective effect sizes. All impact response parameters had a p-value of < 0.001 . The modified shoulder pads consistently reduced impact severity across all parameters (Figure 5).

Table 1: Head kinematic values were used to quantify impact response. All impact response parameters had p-values < 0.001 . Reductions in PLA, PRA, PRV and an increase in duration were identified. PLA and PRV saw a 31% and 28% reduction, respectively, while PRV only saw a 10% reduction. The duration was increased by 40%.

Pad Type	PLA (g's)	PRA (rad/s ²)	PRV (rad/s)	Duration (ms)
Control	29.4 ± 4.25	1960 ± 371	22.8 ± 2.32	24.8 ± 4.98
Modified	20.3 ± 2.14	1396 ± 197	20.4 ± 2.05	34.8 ± 2.36
$\Delta\mu$ (CI)	$-9.13 (-\infty, -7.25)$	$-565 (-\infty, -435)$	$-2.42 (-\infty, -1.54)$	$9.96 (8.06, \infty)$

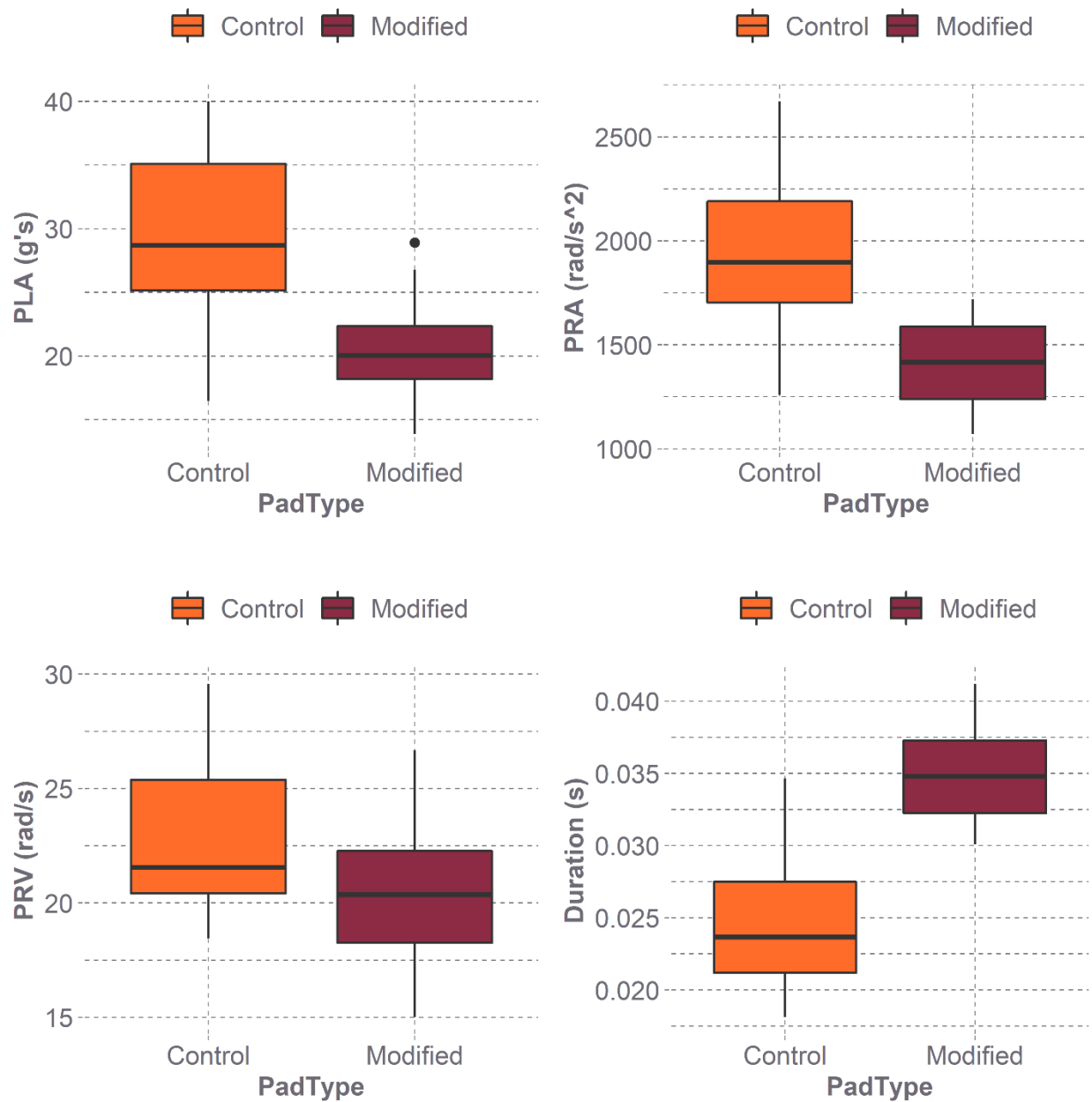


Figure 5: Boxplots of head impact response parameters that highlight the distribution of the two different shoulder pad variations. The modified shoulder pad showed a reduced linear acceleration (top left), rotational acceleration (top right), rotational velocity (bottom left), and an increased duration (bottom right), and reduced variance compared to the control pad.

Impact response corridors were developed for linear acceleration, rotational acceleration, linear velocity, and rotational velocity. The impact corridors give a range of expected responses that can be used to inform future testing. The impact response corridors for the two pad models are shown in Figure 6. The control pad was characterized by a shorter duration and higher magnitude pulse for both linear and rotational acceleration, whereas the modified pad's extended duration helped reduce its overall magnitude. The shaded region is the range of acceptable values for the respective model's impact response, which was defined by plus or minus one standard deviation. The line within each region is the mean impact response for the respective shoulder pad variation.

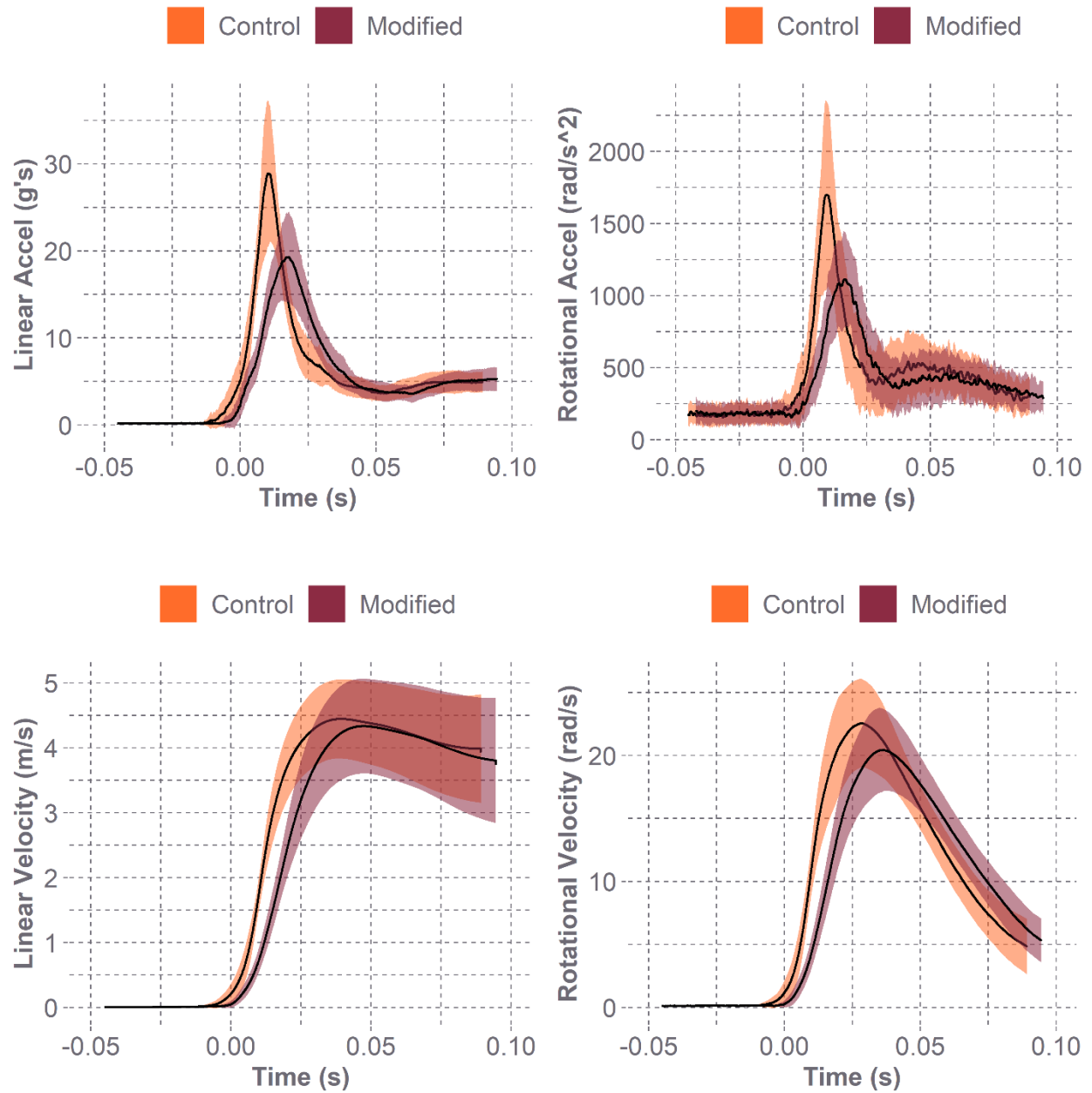


Figure 6: Impact response corridor of resultant linear acceleration (top left), rotational acceleration (top right), linear velocity (bottom left), and rotational velocity (bottom right) for both shoulder pad models. The linear and rotational acceleration corridors highlight the ability of the modified shoulder pads to extend impact duration and reduce magnitude.

DISCUSSION

This study identified differences in head impact response between shoulder pad configurations. Results agreed with the previous findings on hockey shoulder pad impacts, where a 25% reduction in PLA and a 12.4 % reduction in PRV were observed [16]. We observed a 31% reduction in PLA and a 10% reduction in PRV. The additional padding in the shoulder pads acted as an impact modulator which elongated the impact duration by an average of approximately 10 milliseconds, which helped reduce acceleration magnitudes. The accelerations in this study were relatively low magnitude when compared to impacts from on-field data collection [10, 31, 32]. Crisco et al. evaluated over three seasons of collegiate football impacts and found their 95th percentile impact to be associated with accelerations of 62.7 g and 4378 rad/s² [32]. Our control pad impacts only produced 29.4 g's and 1960 rad/s².

Although the accelerations were relatively low in severity, the observed rotational velocities were approaching concussive impact levels. Rowson et al. found rotational velocity for concussive impacts to be around 22 rad/s [11], and our observed average rotational velocity for the control pad were 22.3 rad/s. We noted that the shoulder pad modifications had a stronger effect on reducing head acceleration than on reducing velocity. However, it is unclear what effect this would have on concussion risk because concussive levels were not evaluated and both measures are likely important [18, 33]. In addition, we are unsure how the padding will perform at higher impact speeds. There is a chance of the padding bottoming out, causing it to underperform at high velocities, as seen by Kendall et al. [17]. Overall, the findings show that shoulder pads can reduce head kinematics in STH impacts and warrant further testing at higher impact speeds to assess padding performance at concussive levels.

This study had multiple limitations. First, the study was limited in its ability to fully replicate in-game impact severity. The testing was conducted in a laboratory environment that limited space for the participants to gain speed before striking the dummy. To ensure safety throughout testing, participants were given instruction to only hit the dummy as hard as they felt comfortable. The impact speeds did not reach the levels of magnitude that have been reported with concussive impacts. The average impact speed in this study was 5.8 ± 0.3 m/s, whereas Pellman et al. found the average impact speed for their concussive impacts to be 9.3 ± 1.9 m/s [2]. Due to narrow range of impact speeds seen in our study, we were limited in making assumptions of the performance of the pads at higher impact speeds. Further testing is necessary to understand if the reductions we saw in our study are consistent across a wider range of impact speeds.

The biofidelity limitation of the test dummy should also be taken into consideration. Although crash test dummies are designed to replicate the human body, they are limited in their ability to replicate the soft tissue response to impact. We are unsure how well the dummy simulates the human response for the STH impacts seen in this study. Begonia et al. showed that certain loading directions can have an effect on head kinematics depending on the neck surrogate used [34], inferring test dummies may not be able fully replicate the characteristics of a human body. It is possible the stiffness of the Hybrid III neck and its response for lateral impacts could have contributed to the low accelerations with high rotational velocities.

Another limitation of this study was the consistency of participants' striking technique and impact location. Participants were given a target to aim for on the head with instruction to strike with the top flap of the shoulder pad, yet there was variability in where they struck the side of the head and their technique for a shoulder impact. Each impact was reviewed via high-speed video analysis to ensure that proper contact occurred and to identify any irregularities. Overall, the

impacts in this study occurred within an acceptable range of the upper side of the head. The use of paired tests for statistical analysis was implemented to mitigate the effect that individual variance in technique had on the comparison between shoulder pads. Additionally, the variability of technique was partially beneficial as it developed the corridors to represent the variance present in live impacts. We also wanted to note that ordered effects were not accounted for within this study. Participants had ample time to practice impacts prior to data collection, and we did not see any differences between the impact speeds between the two shoulder pads that would indicate differences due to testing order.

This study acted as the first step into understanding the role of shoulder pads in reducing head injury risk. The impact response corridors can be used to inform a controlled lab test setup that replicates STH impacts, which would allow high impact speeds to be evaluated. The controlled test setup will allow for further testing to better understand the performance of additional padding in higher-severity impacts and the capability of reduced shoulder pad stiffness to reduce concussion risk in STH impacts. The laboratory setup would allow investigation into other aspects of STH impacts such as varying impact location on the head, varying impact location on the shoulder, comparing shoulder pad types, varying pad modifications or material characterization, etc. and help to fully understand what changes can be made to improve player safety.

CONCLUSION

This study identified the capability of additional padding in football shoulder pads to reduce head kinematics in STH impacts and recommends impact testing at higher speeds to understand how shoulder pad variations will perform at concussive level impacts. Results showed that reduced stiffness in the shoulder pad reduced linear and rotational accelerations by 31% and 28%, respectively, with a 40% increase in impact duration and a 10% reduction in rotational velocity. Impact response corridors developed in this study help characterize the average head response curves while highlighting an acceptable margin of variance. The corridors could be used to establish controlled experimental test setups that replicate STH impacts, which could allow the opportunity to evaluate the effect of shoulder pad stiffness on head impact response at higher impact speeds and, ultimately, concussion risk. Overall, this study showed promising data that football shoulder pad stiffness is capable of reducing head accelerations and overall impact severity for STH impacts and encourages further research into shoulder pad design as a method of concussion risk mitigation in football.

CHAPTER 3

SUMMARY OF RESEARCH

There are no standards or certifications for shoulder pad design or research on STH impacts, however studies have shown that STH impacts are a mechanism of injury for a large portion of concussions in the sport. The current research presents evidence that football shoulder pad design and stiffness can reduce head kinematics in shoulder-to-helmet impacts. This study identified that shoulder pads may be a way to further reduce concussions in football, and acts as the first step to understanding the association of shoulder pad stiffness and concussion risk.

The research study aimed to first replicate STH impacts to gather quantifiable information that would allow a comparison of shoulder pad variations and their effect on head impact response. Testing showed a reduction in magnitude for all head kinematic parameters for variation with additional padding, and defined impact response corridors for both pad variations. We noted that the observed impacts did not reach concussive-level impact speed or magnitude, yet the corridors can be used to establish a controlled laboratory setup that can evaluate pad performance for concussive-level impacts.

PUBLICATION PLAN

The plan is to have the proceeding chapter published in The Journal of Applied Biomechanics, a scientific, peer-reviewed journal.

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