

## A Descriptive Video Analysis of Helmet Impact Cases in North American Youth Football Players

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### ABSTRACT

**Background:** Detailed characterization of on-field helmet impacts in football through video analysis has mostly been limited to professional games due to the availability of high quality, multi-view video (e.g., broadcast footage). Few studies have assessed youth football helmet impacts using video-based methods, often with only a single-camera view. **Objective:** A multi-camera approach was used in this observation-based study to describe the mechanisms and situational factors of in-game helmet impacts experienced by youth football players. **Methods:** A descriptive video analysis was performed in which video of three games from two old divisions (game A: 9–12 years; games B and C: 13–14 years) was reviewed and parameters related to all cases of observed helmet impact were documented. **Results:** Overall, 95 helmet impact cases were identified (single helmet contact: 81.1%; multiple helmet contacts: 18.9%), with 115 helmet contacts. Helmet-to-ground contacts were most common (59.1%), followed by helmet-to-helmet (24.3%) and helmet-to-body (16.5%). Helmet impact cases generally occurred during a rush play (67.4%) and were concentrated in the mid-field (81%). Helmet contact locations were predominantly distributed between the rear (upper) (28.7%) and side (upper) (27.8%) helmet regions. Tackling was the most frequent activity leading to helmet impact (41.1%). **Conclusion:** These findings offer detailed on-field helmet impact characteristics at the youth level that can help inform athlete safety improvement efforts.

**Key words:** Youth Sports, Football, Methods, Observation

### INTRODUCTION

Descriptive video analysis has played an important role in characterizing real-world helmet impacts in the sport of football, which has informed efforts to improve athlete safety through training and education, policy and rule changes, as well as protective equipment innovations. This type of observational research has mostly been limited to examining cases of helmet impact in National Football League (NFL) players (Clark et al., 2017; Lessley et al., 2018; Lessley et al., 2020; Pellman et al., 2003) due to the availability of network broadcast footage and other sources that provide high-quality video with multiple views of each play (e.g., All-22 game tape, NFL Films footage, etc.).

Pellman et al. (2003) reviewed game video of severe and concussive impact cases to classify the location and source of the initial helmet contact sustained by the struck player between the 1996 and 2001 NFL seasons. The majority of the viable cases for analysis were reported to involve helmet-to-helmet impact (61%), a finding that was later supported by supplementary epidemiological work using standardized reporting forms to analyze patterns of concussion over the same 6-year period (Pellman et al.,

2004). On-field characteristics of concussive impact cases in NFL games were further explored in two separate descriptive video analysis studies by Clark et al. (2017) and Lessley et al. (2018) that spanned the 2010–2011 to 2013–2014 and 2015–2016 to 2016–2017 seasons, respectively. Relative to prior work (Pellman et al., 2003; Pellman et al., 2004), the main findings from each study similarly observed a marked decrease in helmet-to-helmet impacts among concussed NFL players with a general increase in the number of helmet-to-body and helmet-to-ground impacts overall. The reduction was attributed to the development and implementation of new and revised rules in the NFL over the past two decades which were intended to address concussion incidence and improve player safety by mitigating exposure to severe helmet-to-helmet impacts. A detailed characterization of position-specific circumstances linked to concussion cases from NFL game video has also been completed by Lessley et al. (2020) with the aim of highlighting helmet design considerations unique to each player position.

The use of video analysis to investigate helmet impacts in traditionally untelevised football populations (e.g., youth athletes) has been limited. Research efforts to understand the

biomechanics of helmet impacts experienced by youth football players ( $\leq 14$  years) has been largely accomplished via sensor-driven data from helmets instrumented with accelerometer arrays, wherein video data are solely used to verify sensor recordings (Cobb et al., 2013; Daniel et al., 2014; Kelley, Kane, et al., 2017; Kelley, Urban, et al., 2017; Young et al., 2014). The few studies that have utilized video as a tool (in combination with sensor data) to examine youth football helmet impacts have primarily focused on high-magnitude impacts ( $\geq 40g$ ) and used a single-camera system to view the play on the field, limiting the data that can be obtained (Alois et al., 2019; Campoletano et al., 2017; Le et al., 2021).

Jadischke et al. (2020) developed a novel approach for collecting high-quality video data that used multiple stationary action cameras to analyze head and body impacts in non-tackle American 7v7 football games for youth and varsity-aged players. This approach circumvents common issues of single-camera video analysis, mimicking professional sport by providing multiple views of the field which offers advantages such as: 1) differing camera angles for more detailed characterization of impact cases; 2) a reduced likelihood of excluding cases of interest because of view obstructions (e.g., other players, referees, etc.); and 3) eliminating the concern of missing cases that occur away from the ball (e.g., downfield blocking) due to tracking play development.

Gyemi et al. (2021) recently adapted this multi-camera approach to quantify 3D helmet velocities of helmet-to-ground impact cases from game video of three youth football competitions. The purpose of the present study was to: 1) expand on this work by performing a descriptive video analysis of the mechanisms and situational factors for all cases of observed in-game helmet impact; and 2) address the relative lack of data related to the on-field characteristics of youth football helmet impacts using a research perspective (i.e., multi-view video) that, to date, has been limited to televised professional football.

## METHODS

### In-Game Video Recording

Video of three youth football games from two old divisions (game A: 9–12 year old division; games B and C: 13–14 year old division) was recorded to conduct an observation-based study via descriptive video analysis. All games took place at the same Canadian football field. A multi-camera approach adapted from Jadischke et al. (2020) was used to capture the game video; details of this data collection have been previously described (Gyemi et al., 2021). Eleven stationary action cameras (GoPro HERO6; GoPro, Inc., San Mateo, CA, USA) with  $41^\circ$  field of view (FOV) lenses were positioned around the south half of the field of play. Each side line had four cameras separated by 15-yard intervals with three cameras placed across the back of the end zone. The camera locations were selected to optimize the number and quality of available camera views on the targeted area of field while limiting interference with the game-day environment. Video for all three games was recorded at 2.7 K resolution and 120 frames per second (fps) with a shutter speed of 1/1920 second (s) (Jadischke et al., 2019). For games B and C, an overall view

of the field was also captured using an additional camera (4K/60 fps, 1/960 s) with a wide-angle lens ( $120^\circ$  FOV) located near the stadium press box. Data collection procedures for this study were cleared by the Research Ethics Board of the affiliated university (REB# 19-094). Written consent was obtained from the President of Football Operations for the home team on behalf of the players, and verbal consent was obtained from the players and teams. The game video that was recorded using the multi-camera approach described in the current study occurred alongside the compulsory recordings that are always made by each team for later film study.

### Video Analysis Procedures

The overall framework and standardized terminology used in the present study utilized aspects of past descriptive video analysis work characterizing sport-related head impacts (Clark et al., 2017; Jadischke et al., 2020; Lessley et al., 2018). Game video was reviewed to identify all cases of helmet impact in which clearly visible contact with another helmet, the ground or body part was observed in at least one camera view. Game situation parameters for each helmet impact case were initially documented, such as game and play number, time of game, play type (rush, pass, kickoff, punt, field goal/extra point) and player position (offense, defense, special teams). Yardage lines and lateral positions across the field were used to reference the approximate field location where the impact occurred. Based on this location, three-second video clips were extracted from all available camera views ( $41^\circ$  FOV) that captured the helmet impact case for the subsequent video analysis. Additional observations of whether a player sustained a potential head injury were also recorded. Injury cases were defined as any visible signs of neurologic impairment or injury behaviour (e.g., loss of consciousness, hands on head, etc.) immediately following a helmet impact that resulted in the stoppage of game play or on-field medical attention.

Two trained raters independently reviewed each helmet impact case using a series of predetermined descriptive

**Table 1.** Descriptive video analysis parameters

Parameter	Categories
Contact type	body-to body (B2B), body-to-ground (B2G), helmet-to-ground (H2G), helmet-to-helmet (H2H), helmet-to-body (H2B)
Helmet contact source	helmet, ground, shoulder, arm, torso, thigh, knee, other
Helmet impact activity	tackled, tackling (success/fail), blocked, blocking, trip/fall, diving/leaping, other
Detailed helmet contact location	top, front, facemask (upper edge), facemask (central), facemask (side edge), side (upper), side (lower), rear (upper), rear (lower)
General helmet contact location	top, front, side, rear

H2H impact involves a 'striking' and a 'struck' player.

For general helmet contact locations: top = top, front = front, facemask (upper edge), facemask (central); side = facemask (side edge), side (upper), side (lower); rear = rear (upper), rear (lower).

parameters (Table 1). Open-source software (VLC media player; VideoLAN) was used to view the video clips, which permitted frame-by-frame analysis and the capacity to freely pan, zoom and adjust playback speed. The type of contact that occurred during each case was classified sequentially as: body-to-body (B2B), body-to-ground (B2G), helmet-to-helmet (H2H), helmet-to-ground (H2G) and/or helmet-to-body (H2B). For cases involving multiple helmet contacts, the contact subjectively viewed to be the most significant in terms of impact severity, based on the available video evidence, was identified as the primary helmet contact. Impact activity described the action of a player that led to the helmet impact case. Impact source referred to the resultant entity that contacted the helmet (i.e., another helmet, the ground or a body part). Detailed and generalized helmet regions were used to determine the location of each contact on the helmet. Detailed contact locations included nine regions on the helmet shell and facemask (Figure 1) that were based upon prior video analysis work (Lessley et al., 2018). A 5-point rating scale (5 = excellent, 4 = good, 3 = fair, 2 = poor, 1 = very poor) was used to account for rater confidence in identifying these helmet contact locations. General contact locations were also recorded by condensing the detailed contact locations into four broad helmet regions (top, front, side, rear). The results of each rater were cross-checked to assess their agreement. A third rater acted as the adjudicator to resolve any discrepancies in the data and reviewed all cases in which the average confidence scores for detailed contact locations between the raters was  $\leq 3$  to verify the helmet region selected.

### Statistical Analysis

Descriptive statistics were used to summarize the results of the video analysis as frequencies in both counts and percentages (Microsoft Excel 2019; Microsoft).

## RESULTS

A total of 95 helmet impact cases were observed across the three youth football games (game A,  $n = 29$ ; game B,  $n = 43$ ; game C,  $n = 43$ ) with 77 (81.1%) cases involving a single helmet contact and 18 (18.9%) cases involving two or more helmet contacts (Table 2). Only two (2.1%) helmet impact cases were associated with a potential head injury; both cases occurred in game B from a H2H contact during a failed tackling attempt.

### Helmet Contact Type

For all helmet contacts identified ( $n = 115$ ), H2G contacts were most common ( $n = 68$ , 59.1%), followed by H2H ( $n = 28$ , 24.3%) and H2B ( $n = 19$ , 16.5%) (Table 3). Helmet contact with the ground most frequently occurred as the third contact in the progression, wherein 41 (43.2%) of the 95 helmet impact cases demonstrated a B2B-B2G-H2G contact sequence.

### Game Situation

All but one helmet impact case for game A occurred during a rush play ( $n = 25/26$ , 96.2%); greater variation in the type of play was shown for the helmet impact cases in games B and C ( $n = 69$ ) (rush:  $n = 39$ , 56.5%; pass:  $n = 18$ , 26.1%; kickoff:  $n = 10$ , 14.5%; punt:  $n = 2$ , 2.9%). Overall, offensive ( $n = 43$ , 45.3%) and defensive ( $n = 39$ , 41.1%) positions shared a relatively even distribution of helmet impact cases; special teams roles accounted for 13 (13.7%) cases. Grouping the approximated field locations for each helmet impact case into 20 zones on the targeted half of the field (Figure 2) revealed that 77 (81%) of the observed cases occurred in the mid-field, with the majority focused in the region between the center hash marks. These general field locations were consistent for both offensive and defensive player helmet impacts.

### Helmet Contact Location

The distribution of detailed contact locations for all helmet contacts observed ( $n = 115$ ) showed that the rear (upper) ( $n = 33$ , 28.7%) and side (upper) ( $n = 32$ , 27.8%) regions of the helmet shell were the most frequently contacted (Figure 3), and were largely the result of H2G contact (Figure 4). Regions of the facemask and helmet shell making up the front of the helmet incurred 30.4% ( $n = 35$ ) of all helmet contacts (front helmet shell: 9 [7.8%]; facemask (central): 16 [13.9%]; facemask (upper edge): 10 [8.7%]) from a variety of sources, collectively. Only one helmet contact (0.9%) occurred to the top of the helmet.

### Activity Leading To Helmet Impact

Tackling an opposing player or being tackled accounted for 39 (41.1%) and 31 (32.6%) of the 95 helmet impact cases identified, respectively, with most cases for these

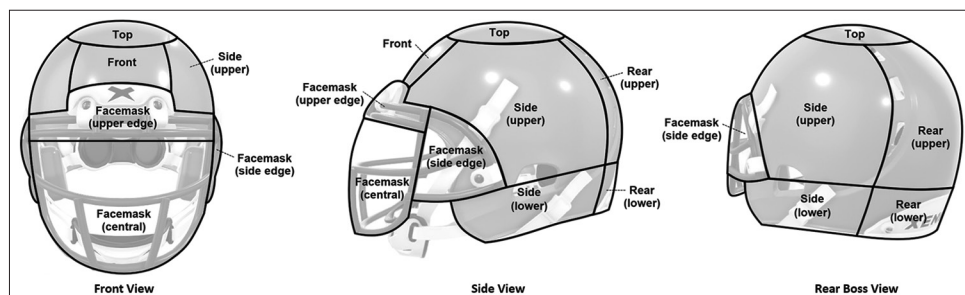


Figure 1. Illustration of the detailed contact locations on the helmet shell and facemask (adapted with permission from Lessley et al., 2018)

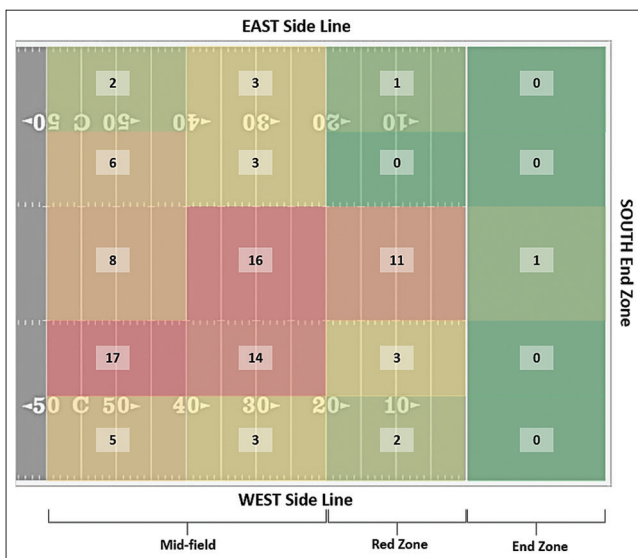


**Table 2.** Frequency (%) of helmet impact cases involving single and multiple ( $\geq 2$ ) helmet contacts overall and for each game (game A: 9-12 year old division; game B and C: 13-14 year age division)

Helmet Impact Cases	Game A		Game B		Game C		Overall	
Single Contact	23	(88.5%)	28	(80.0%)	26	(76.5%)	77	(81.1%)
Multiple Contacts	3	(11.5%)	7	(20.0%)	8	(23.5%)	18	(18.9%)
Total	26		35		34		95	

**Table 3.** Frequency (%) and type of helmet contact (s) (H2H: helmet - to - helmet; H2G: helmet-to-ground; H2B: helmet-to-body) overall and for each game (game A: 9-12 year old division; game B and C: 13-14 year old division)

Helmet Contact	Game A		Game B		Game C		Overall	
H2H	4	(13.8%)	12	(27.9%)	12	(27.9%)	28	(24.3%)
H2G	21	(72.4%)	23	(53.5%)	24	(55.8%)	68	(59.1%)
H2B	4	(13.8%)	8	(18.6%)	7	(16.3%)	19	(16.5%)
Total	29		43		43		115	

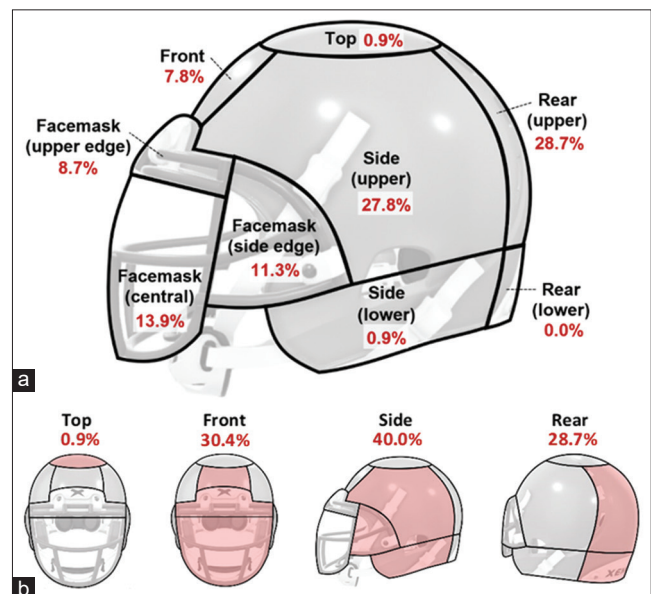


**Figure 2.** Heat map depicting the distribution of helmet impact cases ( $n = 95$ ) by field location

activities involving a primary helmet contact with the ground (Figure 5). The 9-12 year old players (game A,  $n = 26$  cases) most frequently experienced helmet impact from being tackled ( $n = 11$ , 42.3%). The 13-14 year old players (game B and C,  $n = 69$  cases) more commonly sustained helmet impact from the act of tackling ( $n = 30$ , 43.5%), in which successful tackles ( $n = 21$ , 30.4%) had more than double the cases than failed tackles ( $n = 9$ , 13.0%). For helmet impact cases categorized as ‘other’ ( $n = 9$ ), all primary H2G and H2H contacts were the result of a quarterback knockdown ( $n = 6$ ) or ball carrier running through a failed tackle ( $n = 3$ ), respectively.

**DISCUSSION**

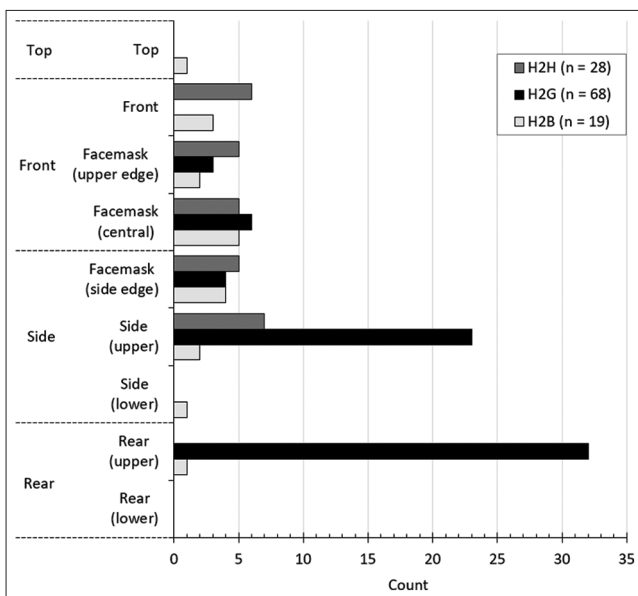
This study presents a descriptive video analysis of helmet impact cases from three youth football games ( $\leq 14$  years old). The aim of this work was to use a multi-camera approach to provide further context of the mechanisms and situational factors associated with in-game helmet impacts experienced by youth players, similar to previous studies in



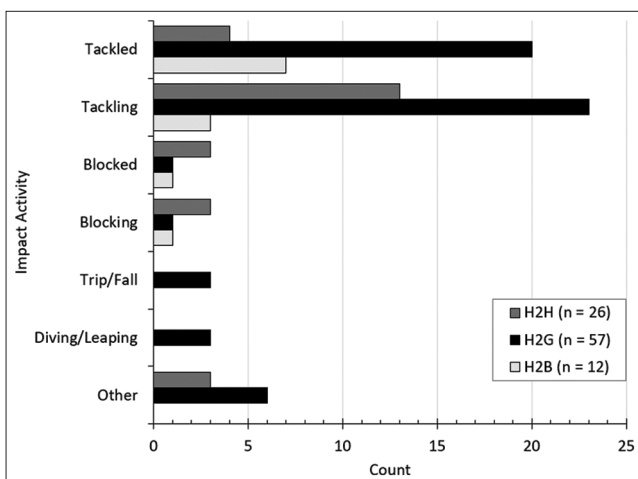
**Figure 3.** Percentages of helmet contacts ( $n = 115$ ) for detailed (a) and general (b) helmet contact locations on the helmet shell and facemask overall

professional football (Clark et al., 2017; Lessley et al., 2018; Lessley et al., 2020; Pellman et al., 2003). Overall, the majority of helmet impact cases identified occurred during a rush play and were concentrated around the mid-field. The most frequent type of helmet contact was H2G, typically following a B2B and B2G contact. Helmet contact locations were predominantly distributed between the upper regions of the rear and side helmet shell across each game. Tackling or being tackled by an opposing player were the most common activities leading to helmet impact.

Prior studies that have used single-camera video analysis to describe on-field characteristics of youth football helmet impacts have found varying results. Le et al. (2021) reported that the most common source of in-game helmet impact for a team of 10- to 11-year-old youth football players wearing Triax SIM-G sensors (14g minimum threshold) was H2B (45.2%), followed by H2H (31.9%) and H2G (17.8%). This opposes the results reported here, which found H2G contact to be the leading type of helmet contact observed across all



**Figure 4.** Helmet contacts ( $n = 115$ ) for detailed and general helmet contact locations stratified by helmet contact type (H2H: helmet-to-helmet; H2G: helmet-to-ground; H2B: helmet-to-body)



**Figure 5.** Primary helmet contacts ( $n = 95$ ) for impact activity stratified by helmet contact type (H2H: helmet-to-helmet; H2G: helmet-to-ground; H2B: helmet-to-body)

games (59.1%). For a sample of youth football players aged  $12.6 \pm 1.3$  years wearing instrumented helmets (Head Impact Telemetry (HIT) System), Alois et al. (2019) determined that H2H contact accounted for 71.9% of in-game impacts; however, this study focused on high-magnitude impacts ( $\geq 40g$ ) involving intentional use of the head, which does not align with H2G impact mechanisms. The higher proportion of H2G contacts observed in the present work could be attributed to the differences in using a video-based compared to a sensor-based approach for identifying cases of helmet impact (Kuo et al., 2018), especially since the exposure data consists of all visually observable instances of physical helmet contact that may not have met the linear acceleration thresholds of these sensor-based studies. The two helmet impact cases resulting in potential head injury in this study

involved significant H2H contact, reflecting the main type of impact linked to concussion in youth football (Chrisman et al., 2019; Kontos et al., 2013).

Helmet impact cases predominantly occurred during a rush play; a typical offensive strategy at the youth level. Passing emerged as a more prominent play type for cases of helmet impact in games B and C, highlighting the progression in the level of play between old groups. The location of helmet impact cases on the field showed similar trends for both offensive and defensive players, with 81% occurring in the middle of the field outside of the red zone and end zone. Field locations reported from NFL video review of concussive impacts found that 66.7% of concussions occurred between the offensive and defensive 20-yard lines (Clark et al., 2017). However, game video in the current study only captured half the field of play and included all types of helmet impact cases (i.e., non-injury and injury). Nonetheless, based on this finding, future research using video to assess in-game youth football helmet impacts should consider including more mid-field camera views to better visualize potential cases.

To the authors' knowledge, this is the first study to quantify the contact locations of youth football helmet impacts using a video-based approach. Previous reports of helmet contact locations for youth populations have relied on generalized estimations (i.e., top, front, side, rear) from instrumented helmets equipped with accelerometer arrays (Cobb et al., 2013; Daniel et al., 2012, 2014; Kelley, Kane, et al., 2017; Kelley, Urban, et al., 2017; Munce et al., 2015; Young et al., 2014), which can be inaccurate and require careful interpretation (Beckwith et al., 2012; Siegmund et al., 2016). Generalized contact locations from the current video analysis showed that the side of the helmet was most frequently contacted overall (40.0%). Detailed contact locations revealed that rear (upper) and side (upper) helmet regions accounted for over half of all helmet contacts observed (56.5%) and 81% of H2G contacts. This reflects the findings from Lessley et al. (2018) that concussive NFL impacts involving helmet contact with the ground were more highly represented by the upper rear and side helmet shell locations. The performance of these helmet regions for attenuating ground impact forces should therefore be considered in future youth-specific helmet designs.

A strike to the ground during the act of tackling was found to be a common mechanism of helmet impact in this study, accounting for approximately 25% of cases overall. This was largely observed in games B and C, wherein players more frequently sustained a H2G contact from a successful compared to a failed tackling attempt. Video analysis of NFL games also determined that tackling was the primary mechanism of helmet impact in professional players; however, this was specific to reported concussion events, wherein H2B impacts (i.e., no pure shoulder contact) comprised the greatest proportion (20%) (Lessley et al., 2018). Efforts to educate and train football players on safe tackling techniques have been an important strategy for reducing helmet impact exposure, with a focus on proper head positioning and use of the shoulder or chest during initial contact (i.e., head-up technique) (Heck et al., 2004). This research suggests that potential helmet inter-

action with the ground following the initial contact from a tackling attempt may require further investigation for youth players, especially considering the unique mechanics of H2G impacts in football (Gyemi et al., 2021; Kent et al., 2020).

This study has several key strengths and also some notable limitations. Helmet impact cases identified for video analysis could be examined in greater detail without the drawbacks of single-camera setups that utilize panning and zooming lenses with lower frame rates since multiple fixed lens, stationary cameras were used that recorded video at 120 fps. However, it is important to note that the results of this study are based on only three full games of video data. Furthermore, the camera layout was constrained to half the field to ensure multiple views of any potential helmet impact case; had the games been played on an American (120 x 53 1/3 yards) rather than a Canadian (150 x 65 yards) football field, more field coverage may have been possible. For these reasons, the generalizability of the findings is limited to the video data available for review and epidemiological measures (e.g., impact exposure rates) could not be reported.

The authors acknowledge the subjectivity of this video analysis. Unlike sensor-based studies, identification of helmet impact via video favours skill positions (i.e., “non-linemen”) and open-field impacts (Pellman et al., 2003) as the line of scrimmage has less clear views due to close, multi-player action. Moreover, despite the use of multiple field-level cameras, occasional view obstructions (e.g., referee interference, etc.) were still evident. Consequently, even though helmet impacts across all player positions were considered in the video review, some selection bias may have been present in the dataset; therefore, positions were limited to offensive, defensive or special teams roles. The inclusion of supplementary overhead views could help mitigate this issue in future work. Impact severity was not measured in this study as all cases of observable helmet impact were documented, regardless of whether a head injury was present or not. However, documenting all helmet impacts, in spite of the perceived severity, could prove to be valuable at the youth level.

## CONCLUSION

The multi-camera approach presented here offers a unique solution for acquiring high-quality multi-view video that can be used to characterize on-field helmet (or head) impacts in untelevised sport populations, such as youth football. The results of this descriptive video analysis demonstrated the significance of H2G impacts in youth football game play, and that special attention may be warranted for the performance of the upper rear and side regions of the helmet shell against turf (i.e., ground) impact. This research also emphasized the importance of tackling as a mechanism of in-game helmet impact for youth football players, wherein safe tackling techniques should consider methods of mitigating H2G impact in addition to H2H impact. Key situational factors of helmet impact included rush plays and impact locations in the mid-field, which are both expected for this old and skill level. This study represents a promising first step to building a database of helmet impact cases experienced by youth football players consistent with previous work in the NFL

(Clark et al., 2017; Lessley et al., 2018; Lessley et al., 2020; Pellman et al., 2003), such that head injury characteristics in the youth population can be better understood.

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## Conflict of Interest Statement

Ron Jadischke is employed by Xenith, a manufacturer of helmets, gear and apparel for American football and related sports. Xenith had no influence on the outcome of this study. Danielle L. Gyemi, Claudia M. Town, Yousef J. Alami and David M. Andrews have no conflicts of interest to declare.

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