Title page

Video Analysis of Head Injury Incidents in Equestrian Sports

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Abstract

Current helmet certification tests involve linear impacts to rigid anvils. The associated kinematics by which a jockey falls from a horse while riding are believed to be fundamentally different to those in the certification tests, i.e., they involve oblique falls (falls at an angle) to compliant surfaces. This paper provides primary data from real-world equestrian accidents to characterise such kinematics, and constitutes a basis for future helmet developments and improvements in certification tests. The purpose of this study was to use well-documented video footage of equestrian accidents to characterise associated head injuries. 1,119 equestrian accidents were collected from professionally regulated horse races and eventing during an eight-year period. Head injury incidents were analysed on a frame-by-frame basis to characterise the impact event, location and surface. A total of 73 head injury incidents afforded a set of documentary data that were analysed: these involved 69 concussions, two hematomas, two orbital fractures, a fractured zygoma and a fractured mandible. Based on the results of this study, priorities for future helmet designs and certification tests should be informed by the present findings. Since all of the observed cases involved the head impacting compliant surfaces (turf or sand) in an oblique manner, it is recommended that the protective capacity of equestrian helmets be assessed for oblique impacts to compliant surfaces. Furthermore, since the most frequently impacted locations were the lower region of the helmet and the mid-region on the back of the helmet, it is suggested that additional protection in these areas could be beneficial.

Keywords: Head injury, Concussion, Oblique impact, Equestrian, Helmets

Introduction

Equestrian sports, including horseracing, are popular around the world but are amongst the most hazardous of sports [1]. Fall risks are as high as 140 falls per 1000 rides in jump racing and rates of injuries/fall are as high as 44% in flat racing, while the majority of jockey injuries are caused by falls [2-9]. Of all the injuries in both jump and flat racing populations of amateur and professional jockey, 15% were reported to be concussions [8], of which more than half involved loss of consciousness. In a review [8], all accidental causes of concussion following a jockey falling from their horse were considered (e.g. head impact against ground, horse or a hoof kick, etc.). Head injuries are among the most common types of injuries sustained in equestrian accidents [3,7-11], with 45% of all sports-related TBI being related to horseback riding, notably higher than falls or impacts from contact sports such as football, hockey and soccer, which when taken together, accounted for just 20% of TBIs [2]. Research has identified that multiple concussions over the period of an athlete's career can lead to long term disability [12], which underscores the importance of reducing the occurrence of these injuries. Understanding the characteristics of equestrian accidents that result in head injury can provide important insight for injury prevention efforts [1,8,10,13-16]. A detailed analysis of equestrian accidents can serve to identify common conditions under which head injuries occur and thereby establish priorities for the development of new tests and designs for helmets.

Current equestrian helmet standards typically involve a linear drop test onto a fixed steel anvil [17-19]. In Europe, the headform is dropped unrestrained onto the anvil [17,19], whereas the headform is rigidly secured to the drop carriage in North America [18]. Depending on the standard, impact velocities range from 4.4 – 7.8 m/s with 5.9 m/s being the most common impact velocity [17-19] for equestrian helmet standards. The main pass/fail criterion for the tests is that peak linear acceleration must not exceed 250 – 300 g, depending on the standard. Additional criteria in some standards include requiring the duration for which the linear acceleration exceeds 200 g to be less than 3 ms and the duration for which the linear acceleration exceeds 150 g to be less than 4 – 6 ms [17,19]. Some standards also require additional testing such as drop tests to hazard (i.e., angled) and hemispherical anvils [18]. However, these standard test conditions may not represent actual equestrian accident conditions and, as a result, may not provide the required protection. A helmet should be designed and tested in conditions that are representative of the circumstances in which they are used [20]. If helmets are not designed and tested in appropriate conditions, then they may offer little or no protection under typical impact conditions [21,22]. By studying equestrian accidents, new helmet test standards can be developed which better reflect the conditions of equestrian accidents.

Earlier studies relied on self-reporting (rider) and eyewitnesses to assist in the investigation of head injuries in equestrian sports [2-9,23]. Video analysis, however, allows for a more objective and considered investigation of accident events that occur in a fraction of a second and that may not be reported properly by either a rider or eyewitnesses [13-16,24]. Video analysis of an equestrian accident can clarify specific details including event type, impact location, possible secondary impacts, and can provide greater detail than eyewitnesses or self-reports. Video analysis has been used in other sports, including lacrosse, ice hockey and rugby, to objectively examine event characteristics that caused a head injury [13-16,25,26]. While video analysis has been used in equestrian sports to study injuries to the horse [27,28] it has seldom been used [29,30] to characterize head injury incidents for the rider.

There is a worldwide paucity of equestrian injury data that describes the characteristics of head injury events. The present study uses video analysis to examine the event characteristics of accidents that lead to head injuries in equestrian sports. This information can serve to inform the priorities for future developments in equestrian helmet standards and helmet designs and thus aid in injury prevention efforts.

Material and Methods

The protocol for this study was approved by University College Dublin's Office of Research Ethics (LS-E-18-17-Clark-Gilchrist).

Data Sampling and Sources

Video incidents of equestrian accidents, either in horse racing or in the cross-country phase of eventing, were collected from equestrian governing bodies in Ireland and Britain during the period between August 2011 and May 2018. The sources from which accident data were collected included the Irish Horseracing Regulatory Board (IHRB) in Ireland, and British Eventing, the British Horseracing Authority (BHA) and the British Equestrian Trade Association (BETA). All the data collected from the four sources were combined to form the University College Dublin Equestrian Accident Database[1]. During the collection period (2011-2018) the European helmet standard was changed (in 2016), in which the most relevant change was an increase of the test impact velocity from 5.4 to 5.9 m/s [19,31]. No other policy or practices were changed during the data collection period and regulatory authorities in most European jurisdictions after the introduction of this change permitted the use of helmets certified to either the old or new standard. For horse racing, all available accident videos that involved a head injury were collected. For eventing, however, head injury events were only collected from the cross-country course at which a professional videographer had been present.

[1] Due to data confidentiality, it is not possible to provide complete open access to this entire dataset. Summary data is provided in [29,30]. Further data may be available by contacting the corresponding author directly.

It is reasonable to assume that the proportion of head injury events in eventing would be independent of whether a videographer was present.

Inclusion and Exclusion Criteria

In this study, it was only those videos in which an accident was identified as leading to a head injury that were analysed subsequently. A head injury incident was defined as any accident reported to the on-site certified medical officer and diagnosed by a medical doctor as being a concussion, fracture or hematoma. Head injury incidents included in this study were required to have a clear view of any impact that occurred to the head. If no clear view of a suspected head impact was evident, the case was excluded from the study.

Video and Data Analysis

Video footage of the included accidents was analysed using Kinovea 0.8.20 (open source, kinovea.org). This software was used previously in head injury research to determine impact parameters such as velocity, orientation and location for laboratory experiments [22,29,30,32,33] and computational simulation [34], and has been coupled with on-field measurements using the Head Impact Telemetry (HIT) System [35]. In the present study, video sequences were examined to identify the nature of the impact event (e.g. fall, kick or collision), the location or region of the head that was impacted, and the impact surface (e.g. turf, sand, horse's hoof or horse's leg). Impact location on the helmet was determined using a reference grid illustrated in Figure 1. The reference divided the head into 30 sections. The head/helmet was divided in this manner to distinguish between front, front-boss, side, rear-boss and rear locations, creating eight sections in the transverse plane. From the top of the helmet, each section was created by segmenting the transverse plane in 45° increments. In the sagittal plane, the head was divided by starting at the chin and proceeding superiorly, creating a horizontal section every 6 cm with respect to the 50th Hybrid III headform. This divided the head into four evenly spaced levels plus a smaller 2.5 cm top (crown) level in the sagittal plane. The level of precision in Figure 1 used to report impact location is good and is similar to other studies reporting impact location [15,16,36-39]. Each of the parameters (impact event, location and surface type) was established for each distinct case. For all incidents that satisfied the inclusion criteria, a frame by frame analysis was performed (Figure 2). Videos were recorded at frame rates between 23.97 and 30 fps depending on the video source. The accident video sequences were viewed as often as necessary and at any playback speed, which allowed each impact parameter to be properly established. Descriptive statistics of the outcome measures of interest were determined.

Results

Head Injuries and Impact Events

A total of 111 videos of rider accidents that involved head injury were collected. Figure 3 categorises all 111 of these accident videos according to equestrian sport and head injury. Of the 111 head injury cases, 73 met the inclusion criteria of the present study. As a result, 66% of the head injury cases collected were analysed in this study with the rest excluded due to poor video quality. 55 of these cases involved males while 18 involved females. 10 incidents (male: n = 2; female: n = 8) were from eventing: all of those occurred at a jump. 63 incidents (male: n = 53; female: n = 10) were collected from horse racing, in which 51 (81%) occurred at a jump and 12 (19%) on the flat. Figure 4a presents the proportions of coded head injuries sustained from equestrian accidents. The head and brain injuries sustained included hematomas, concussions, orbital fracture, fractured zygoma and fractured mandible. All of the hematomas resulted from accidents in cross-country eventing involved a fall. All of the fracture injuries occurred in horse racing accidents from either a horse kick or from being stomped on by a horse. Figure 4b presents the breakdown of impact events involved in the head injury incidents. All incidents involved a fall in which the head impacted either turf (n = 66; 90%) or sand (n = 7; 10%). Multiple impacts occurred in 19 cases (26%), in which the secondary and tertiary head impacts (n = 18; 25% and n = 1; 1%, respectively) involved a horse and occurred by either a kick, collision with a horse, or the rider being crushed or stomped on by the horse.

Linear vs. Oblique Impacts

Oblique impacts (defined as when the line of action of the impact force vector does not pass through the centre of mass of the head) occurred from all of the 73 fall accidents, as well as from one collision with a horse and six horse kicks. Linear impacts (correspondingly defined as when the line of action of the impact force vector passes through the centre of mass of the head) occurred in six rider-horse collisions, three horse kicks, and all four incidents where the rider was either crushed or stomped on by the horse.

Impact Locations

The locations of the head that were impacted during these same head injury incidents are shown in Figure 5. In total, 93 head impacts were observed for the 73 cases, i.e., a number of cases involved secondary and tertiary impacts. The most commonly impacted location was the front-boss region of the head (n = 24; 26%), closely followed by impacts to the side of the head (n = 22; 24%). The next most commonly impacted region was the front (n = 19; 20%), followed by the rear-boss (n = 16; 17%), while the region least impacted was the back of the head (n = 12; 13%). With respect to levels in the sagittal plane that were impacted, most impacts occurred to the lower region of the helmet and the mid-region on the back of the helmet (n = 65; 70%). The next highest region was the upper portion of the helmet (n = 19; 20%), while no impacts occurred to the crown or top of the helmet.

Figure 6 shows the breakdown of impact locations by impact event type. For falls, most impacts occurred to the side (n = 18; 26%) and front-boss (n = 18; 25%) regions of the head (Figure 6a). The next most frequently impacted region was the front (n = 15; 21%), followed by rear-boss (n = 12; 16%) and the least impacted region was to the rear (n = 9; 12%). For horse kicks, most impacts were to the helmet (n = 5; 56%), however, impacts also occurred to the facial region (n = 3; 33%) (Figure 6b). In collisions with a horse, most impacts occurred to the rear (n = 3; 38%) and side of the head (n = 2; 25%) (Figure 6c). The one case in which the jockey's head was stomped on by a horse occurred to the side in the L4 region (Figure 6d). The three cases involving the jockey's head being crushed by the horse all occurred to the lower regions of the helmet (Figure 6e).

Discussion

This study examined 73 videos of helmeted head injury incidents during equestrian racing, the results of which indicate deficiencies in current tests and designs for equestrian helmets.

Most Common Impact Event

All equestrian accidents analysed in this study involved a fall in which the rider's head impacted a turf or sand surface in an oblique manner. These results are consistent with previous research which report a fall from the horse and impacting turf or sand surfaces as the main cause of head injury [3,23,40-42]. Future developments in helmet standards could consider the use of an oblique impact [43]. A proposal was recently submitted to the European Committee for Standardization (CEN) by Halldin [44] for oblique impact testing on cycling helmets. It may be possible for that proposed protocol to also be used for equestrian helmets with the addition of a compliant anvil, although this would pose particular challenges that would first require additional research. Alternatively, given that oblique impacts are common in equestrian sports there may be an opportunity to improve the protective capacity of equestrian helmets by means of using materials or designs to attenuate rotational acceleration [42,45,46]. Future work could seek to ascertain the speeds, impact kinematics and clinical outcomes of equestrian accidents through the use of wearable sensors [47-49] or physical and/or computational accident reconstruction methods [50-53]. By developing equestrian helmet standards that account for the loading conditions associated with concussion and other traumatic brain injuries and by attenuating rotational acceleration during impact, future helmet designs should serve to reduce the occurrence of brain injury in equestrian sports.

Multiple Impact Incidents

Multiple impacts occurred in 30% of racing accidents in which secondary and tertiary impacts involved horse kicks, collision with a horse, or the rider being crushed or stomped on by the horse. The use of rigid anvils, particularly if shaped to represent a concentrated load, in current equestrian helmet standards [17,18,54] may help to prevent head injuries from horse kicks when the helmet is struck. However, in this study some horse kicks occurred to the facial region resulting in fractures where the current equestrian helmets offer no protection. Similar reports of fractures due to horse kicks for the unprotected face have previously been noted by Ueeck et al. [55] and it is likely that repeated impacts to a helmet can diminish its effectiveness. A full-face helmet or the addition of a face cage to jockey helmets similar to ice hockey, hurling and lacrosse helmets may be beneficial design characteristics that would protect against these types of injuries, although it is unlikely that such drastic design changes would be adopted within equestrian sports. With regards to being crushed by a horse landing on the jockey, current equestrian standards do not conduct tests that represent the mechanics of these situations and, therefore, the protective capacity of equestrian helmets for this type of impact event is unknown. While current helmet standards involve a quasi-static crush test [17-19,53,56], the present study has shown that crush incidents occur when the horse lands on the jockey's head in a manner that creates a dynamic crush situation [57]. The different loading rates between dynamic and quasi-static crush require different helmet designs or test procedures, since the energy absorbing foam liner is viscoelastic and behaves differently under static and dynamic rates of loading [58,59].

Impact Locations

The lower region of the helmet and mid-region of the back of the helmet were found to be the most commonly impacted areas in equestrian sport head injury incidents. Since 70% of the impacts observed in this study occurred in these regions, additional protection in these areas may help to reduce the risk of head injury. No head injury incidents in this present study were seen to have impacts to the crown (top) of the head. This may be a consequence of equestrian helmet designs, many of which are designed to include a foam block at the crown region that provides additional energy attenuating material and an air gap between the shell and liner of the helmet at the top of the helmet. The air gap and foam block design feature may increase impact energy attenuation for the crown and top region of the helmet and, therefore, may reduce the risk of injury for impacts which occur to these regions of the head. Similar design features may be beneficial for the lower regions of the helmet to reduce the risk of injury, although they would not be appropriate if they led to an increase in overall helmet dimensions or mass.

Limitations

The current study is limited, as the data only reflects head injury incidents that occur during filmed competition. Head injuries also occur during training, while riding out (i.e., exercising) or partaking in other levels of competition that are not filmed and subsequently are not reported in this study, for example fall impacts on rigid surfaces such as concrete or compacted tarmac. Additionally, not all video containing a diagnosed head injury could be analysed, due to a restricted view of suspected head impacts. Head injuries may also have been undetermined or underreported in the present study. Nevertheless, limiting the present study to video data of diagnosed head injuries with a clear view of any head impact allows for confirmation of the impact events associated with head injury incidents. The cohort examined in this study was biased towards males and professional or competitive riders, which is not fully representative of the wider population of riders involved in equestrian sports. The analysis of this study was restricted in this manner since professional horse racing and competitive eventing are often filmed with high definition cameras, whereas this is rarely the case for recreational riding. As a result, the head injury incidents analysed in this study may not represent those sustained by the wider equestrian population. At least these particular cases constitute a well-defined, significant cohort of riders. Finally, 1,008 of the total 1,119 fall accident cases (i.e., 90%) did not involve a head injury. It is likely that a significant, albeit unknown, percentage of these did, however, involve a head impact – those particular cases reflect events where helmets may have prevented an injury.

Conclusion

This study examined 1,119 video sequences from horse racing and cross-country eventing and analysed a comprehensively documented subset of 73 head impact injuries. Several important accident characteristics were apparent which may serve to identify priorities for future helmet design efforts and certification standards developments: (1) all falls involved the head impacting compliant turf or sand surfaces in an oblique manner; (2) multiple impacts occurred in 30% of racing accidents (n = 19/63) in which secondary and tertiary impacts involved a horse kick, collision with a horse, or the rider being crushed or stomped on by the horse; (3) impact locations were most often to the lower region of the helmet and the mid-region on the back of the head. Future helmet designs and certification standards for equestrian helmets should consider these common head injury incident characteristics. Future work could usefully undertake an in-depth analysis of the speeds, impact kinematics and clinical outcomes of such equestrian accidents as have been discussed in this present paper.

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Conflict of Interest

The authors report no conflict of interest.

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Figure Captions

Figure 1: Plan, left and right views of the helmeted head, illustrating the various divisions that were used to identify impact locations for accident reconstruction purposes. In the transverse plane, 8 sections were defined, all of 45° increments.

Figure 2: Frame by frame snap shots (25 fps) of an equestrian jockey accident.

Figure 3: Breakdown of equestrian accident video collected by sport and type of head injury sustained (n = 111).

Figure 4: Breakdown of head injury incident (n = 73) from equestrian sport accidents: (a) head injury type, (b) impact event type.

Figure 5: Illustration of 93 impact locations on the head for 73 equestrian sport head injury incidents. Note that the image collates injuries from both the left and right sides of the sagittal plane.

Figure 6: Illustration of 93 impact locations on the head for 73 equestrian sport head injury incidents separated by impact event: (a) 73 falls, (b) 9 horse kicks, (c) collisions with a horse, (d)1 stomped on by horse, (e) 3 crushed by a horse. Note that the image collates injuries from both the left and right side of the sagittal plane.

Figure 1

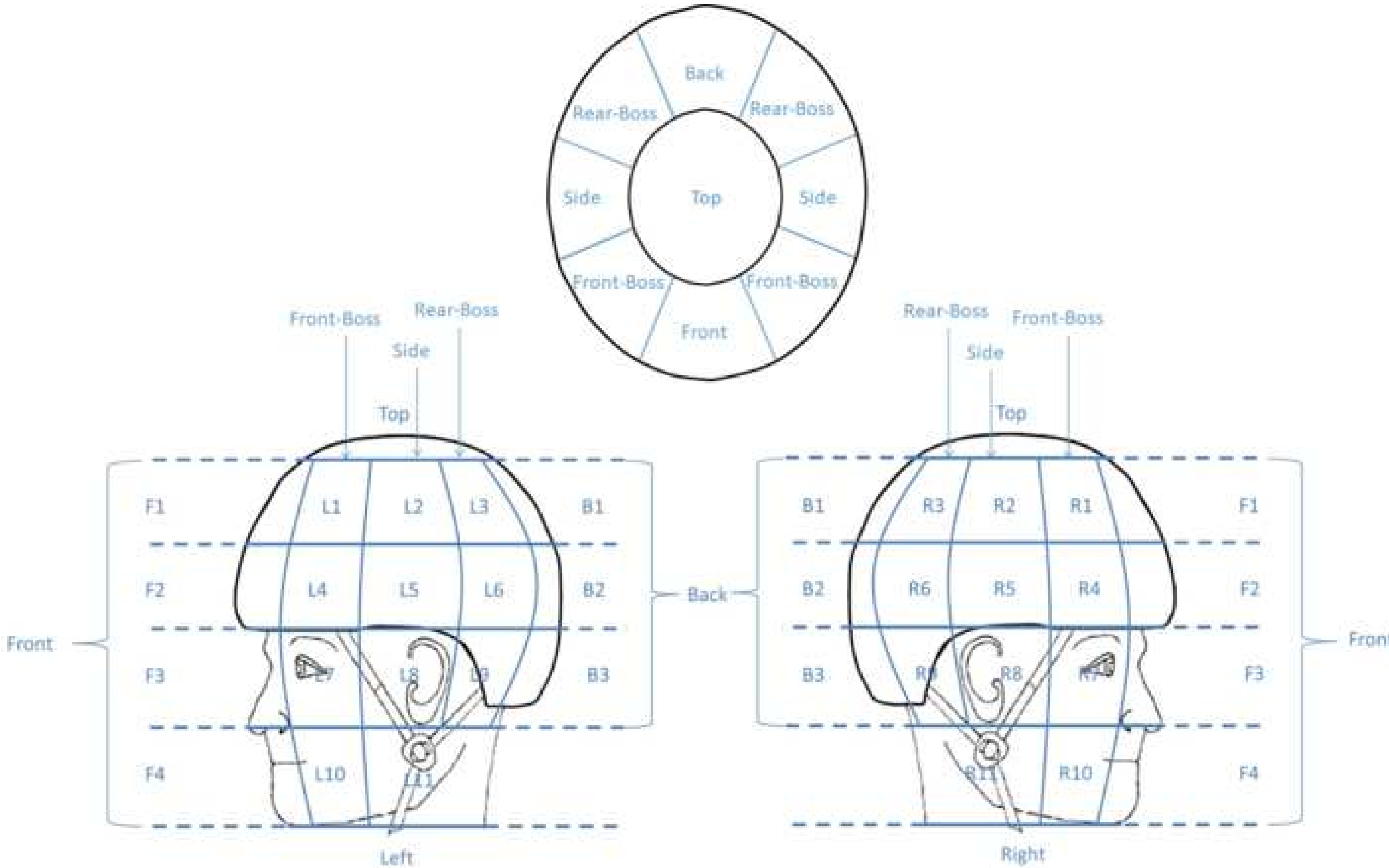
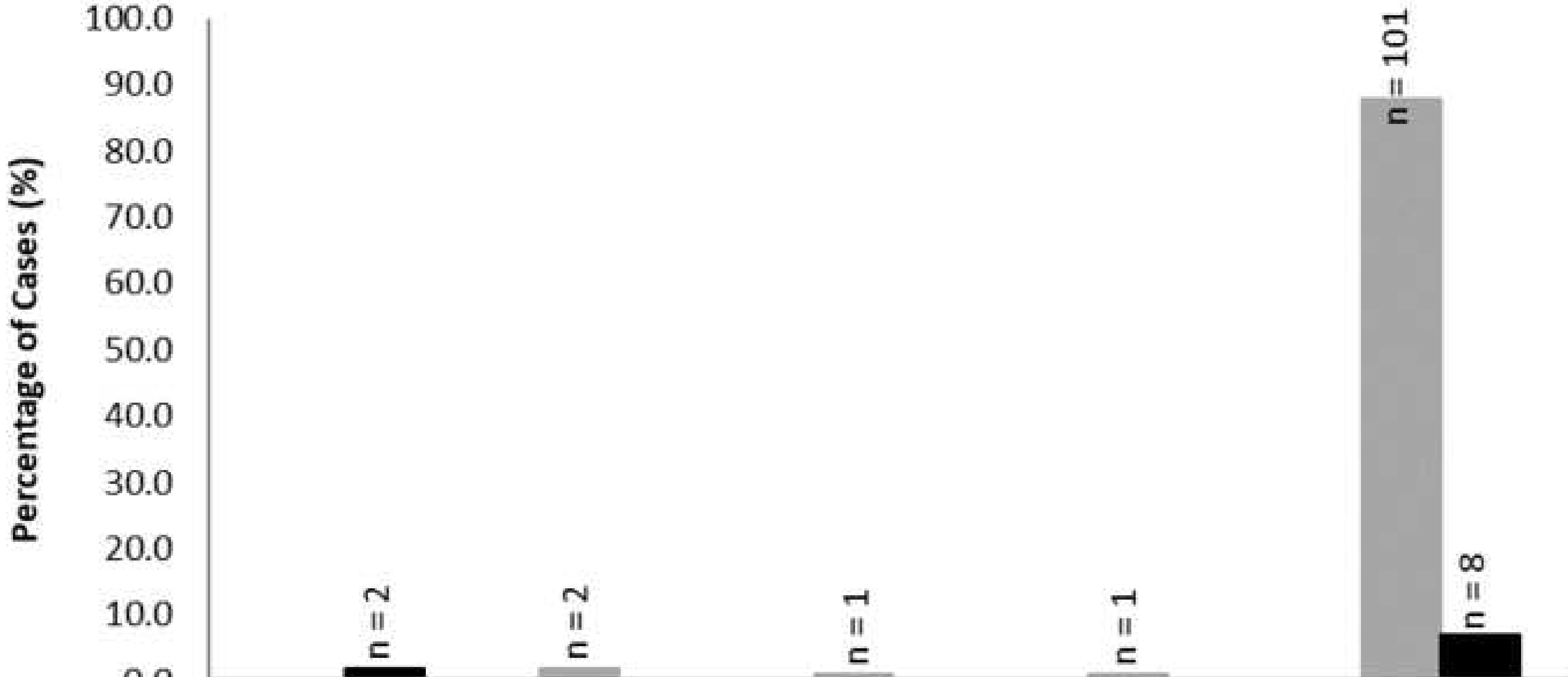

Back
Rear-Boss
Rear-Boss
Side
Top
Side
Front-Boss
Front-Boss
Front
Front-Boss
Rear-Boss
Side
Top
Rear-Boss
Front-Boss
Side
Top
F1
L1
L2
L3
B1
F2
L4
L5
L6
B2
Front
F3
L8
B3
F4
L10
Left
Back
B1
R3
R2
R1
F1
B2
R6
R5
R4
F2
B3
R8
F3
Front
R10
F4
Right

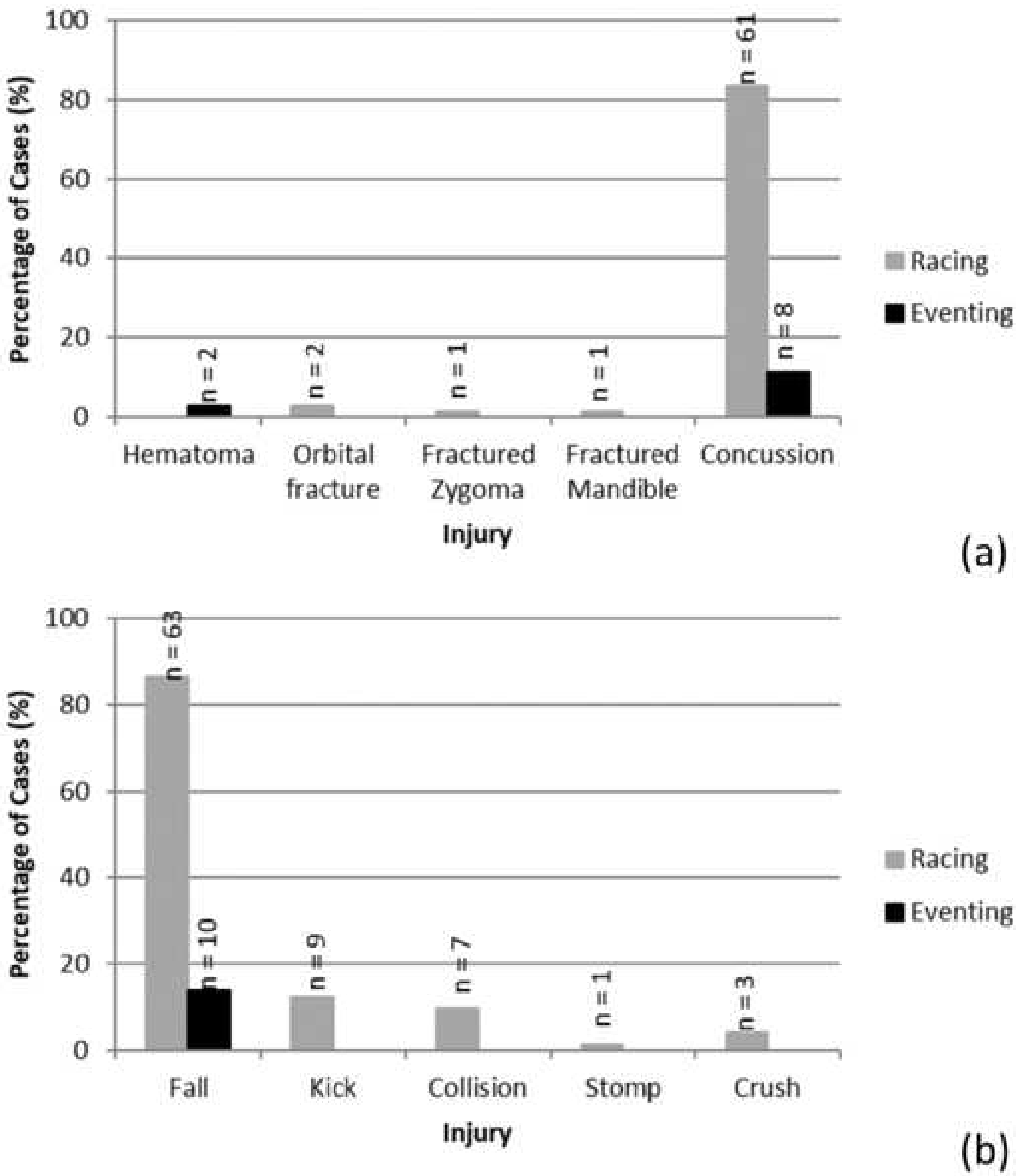
Figure 2

Figure 3



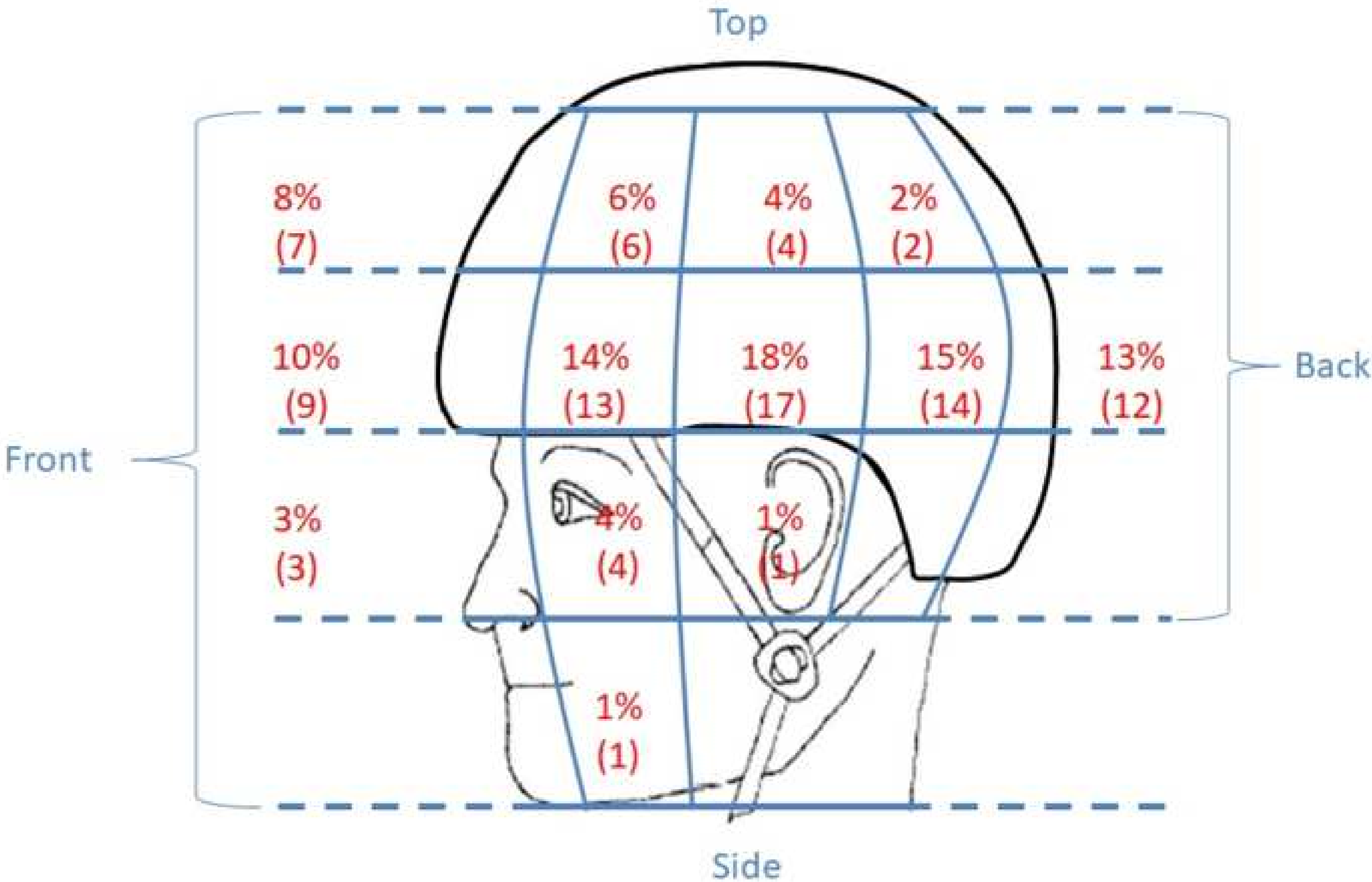
	Haematoma	Orbital fracture	Fractured Zygoma	Fractured Mandible	Concussion
Racing	0.0	1.7	0.9	0.9	87.8
Eventing	1.7	0.0	0.0	0.0	7.0

Figure 4



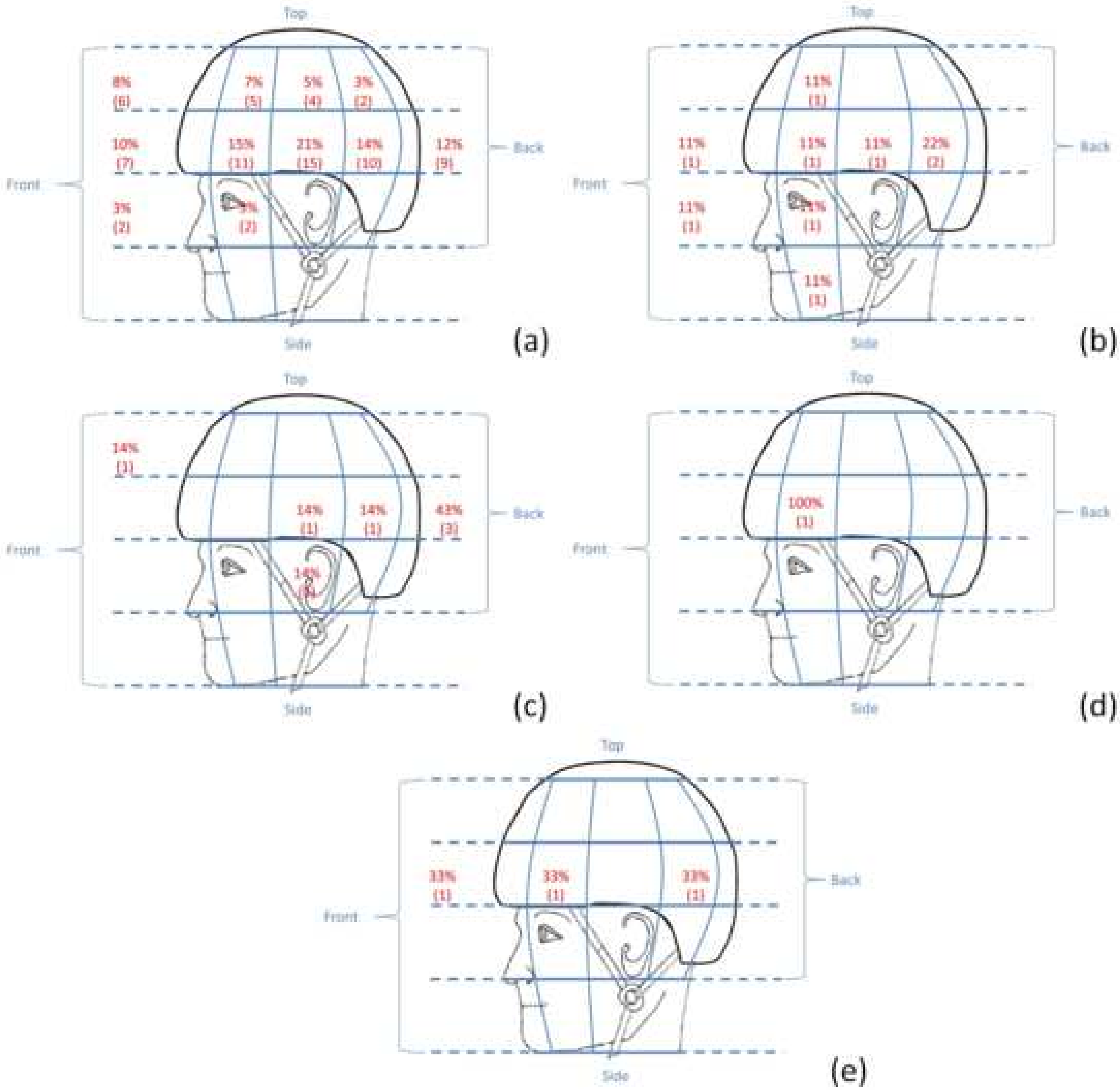
Percentage of Cases (%)
100
80
60
40
20
0
n = 2
n = 2
n = 1
n = 1
n = 61
n = 8
Hematoma
Orbital fracture
Fractured Zygoma
Fractured Mandible
Concussion
Injury
Racing
Eventing
(a)
Percentage of Cases (%)
100
80
60
40
20
0
n = 63
n = 10
n = 9
n = 7
n = 1
n = 3
Fall
Kick
Collision
Stomp
Crush
Injury
Racing
Eventing
(b)

Figure 5



Top
8%
(7)
6%
(6)
4%
(4)
2%
(2)
10%
(9)
14%
(13)
18%
(17)
15%
(14)
13%
(12)
Back
Front
3%
(3)
4%
(4)
1%
(1)
1%
(1)
Side

Figure 6



Top
8%
(6)
7%
(5)
5%
(4)
3%
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10%
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(11)
21%
(15)
14%
(10)
12%
(9)
Back
Front
3%
(2)
3%
(2)
Side
(a)
Top
11%
(1)
11%
(1)
11%
(1)
11%
(1)
22%
(2)
Back
Front
11%
(1)
11%
(1)
11%
(1)
Side
(b)
Top
14%
(1)
14%
(1)
14%
(1)
43%
(3)
Back
Front
14%
Side
(c)
Top
100%
(1)
Back
Front
Side
(d)
Top
33%
(1)
33%
(1)
33%
(1)
Back
Front
Side
(e)