Factors Associated With Head Trauma Among Professional Mixed Martial Arts Athletes.

Peter Scalia
Master's of Science Program in
Interdisciplinary Health Sciences

Interdisciplinary School of Health Sciences
Faculty of Health Sciences
University of Ottawa
Ottawa, Ontario

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Supervisor
Raywat Deonandan, Ph.D.

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Abstract

Background: Chronic traumatic encephalopathy (CTE) is an enigma that has become synonymous with combat sports over the past few decades. Mixed martial arts (MMA) is a combat sport that is growing in popularity world-wide. The objective of this study is to determine the factors associated with head trauma among MMA athletes. Methods: Logistic regression analyses using SPSS 20 was employed to model putative covariates against the dichotomous outcomes of unconsciousness (for the full dataset) and diagnosed concussion (for the enriched subset of fighters who were rendered unconscious). Results: Increasing age, black or African-American ethnicity, shorter rest periods between fights, increasing numbers of significant clinch strikes landed, significant distance body strikes landed and power strikes landed to the body at distance are all factors associated with being diagnosed with a concussion among the fighters rendered unconscious. Conclusion: If bolstered by confirming laboratory and clinical evidence, policies should be developed for implementation by MMA governing bodies to help reduce incidences of head trauma and concussion, built around fighters' demographic and behavioural characteristics. In particular, enforcing a mandatory rest period between fights and placing an upper limit on fighters' age are ideas worth exploring.

Keywords: Chronic traumatic encephalopathy | head trauma | mixed martial arts | combat sport

Contexte: Au cours des dernières décennies, l'encéphalopathie traumatique chronique (ETC) est devenu une énigme synonyme avec les sports de combat. Arts martiaux mixtes (AMM) est un sport de combat qui se développe de façon exponentielle dans le monde entier . L'objectif de cette étude est de déterminer les facteurs associés à un traumatisme crânien chez les athletes de AMM. Méthodologie: Analyse de régression logistique utilisant SPSS 2.0 sera utilisé pour modéliser les covariables contre deux différents résultats dichotomiques. Résultats: L'âge, l'origine ethnique, les périodes de repos entre les bagarres, et plusieurs frappe au corps à distance ou dans le "clinch" sont tous les facteurs associés au fait d'être diagnostiqués avec une ETC parmi les combattants qui ont été rendu inconscient. Conclusion: Les régulations doivent être mises en oeuvre par toutes les administrations qui permettent le MMA pour protéger les combattants à tous les niveaux de la concurrence basée sur les résultats de la présente étude.

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Abbreviations

AE	Athletic Exposure
CDC	Center for Research Control and Prevention
CT	Computerized Tomography
CTE	Chronic Traumatic Encephalopathy
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
ISCF	International Sport Combat Federation
K-D Test	King-Devick Test
KO	Knockout
MACE	Military Acute Concussion Evaluation
MMA	Mixed Martial Arts
NFL	National Football League
UFC	Ultimate Fighting Championship
WEC	World Extreme Cagefighting

Introduction

The meteoric rise of mixed martial arts (MMA) in America and around the world has drawn the ire of various medical groups including the American Medical Association, Canadian Medical Association, British Medical Association, and Australian Medical Association due to the severity of injuries sustained by the athletes during competition (Heath & Callahan, 2013). MMA is a full-contact combat sport that amalgamates facets of boxing, wrestling, karate, taekwondo, jujitsu, Muay Thai, judo, kickboxing, and other martial traditions, suspected of leading to a high rate of head injuries. Also known as cage fighting or ultimate fighting, the history of this sport, characterized by some as vicious, dates back centuries (Heath & Callahan, 2013).

Versions of MMA have existed throughout history. Ancient Greece practiced the Olympic sport of Pankration which allowed fighters to combine grappling and striking techniques to defeat their opponent (Warner, 2014). In sporadic tournaments, throughout the 1900s, combatants with various fighting backgrounds from Europe, the Pacific rim, and Japan would square-off to determine which martial art was the most effective combat-style (Warner, 2014). The inauguration of the Ultimate Fighting Championship in the United States in 1993 was born from so-called "Vale Tudo" competitions that had occurred in Brazil decades prior. In the USA, unified rules for MMA were formulated in 2000 in an attempt to both quell the activity's stigma of "fight to the death" and to begin the process of transforming the practice into a regulated mainstream sport (Warner, 2014). The reputation of MMA improved as weight classes were established, and fights were limited to 3-5 rounds each of five minute duration. Strict regulations such as the use of open-fingered gloves for hand protection and the elimination of certain manoeuvres (for example, head butting) enhanced the protection of the sport's

participants. International acceptance of the sport led to the construction of the very first MMA sanctioning organization called the International Sport Combat Federation (ISCF). In the United States, where the sport is most popular, MMA is governed by the individual state athletic associations who often add further regulations (Warner, 2014). In Canada Bill S-209 was passed on June 5, 2013, to formally decriminalize MMA (Deibert, 2012). This allowed all Canadian provinces the authority to create athletic commissions to regulate and sanction MMA fights (Deibert, 2012). Bill S-209 simply allowed provinces to make it legal on a province-by-province basis. MMA bouts remain illegal in Newfoundland and Labrador, Prince Edward Island, Saskatchewan, Yukon, and Nunavut due to the absence of an athletic commission (Magraken, 2013).

While scores of organizations sponsoring and promoting MMA scatter the globe, the Ultimate Fighting Championship (UFC), headquartered in Las Vegas, is the largest and most prominent MMA promotion company, featuring the world's top-ranked male and female fighters. To many, MMA is synonymous with UFC, as the organization essentially invented the modern version of the sport, with the televised broadcast of their first tournament in 1993.

There are several methods by which a fighter can win his or her MMA match: knockout (KO), decision, stoppage by the referee or ringside physician due to injury or due to a fighter's inability to protect himself or herself, submission, or the corner-man "throwing in the towel" to indicate acquiescence (UFC Canada website, 2014). When a competitor is disoriented or knocked down unconscious it is considered a KO. A technical knock-out (TKO) occurs when the referee ends the combat due to a fighter not being able to defend his or herself due to disorientation. Close to 15% of MMA athletes have a history of being KO'd, and nearly one-third reported a TKO (UFC Canada website, 2014).

Of late, concussions in a plethora of contact sports have proven to be a popular topic for medical research. It is common knowledge that cumulative head trauma related to contact sports is associated with chronic traumatic encephalopathy (CTE) (Bernick et al., 2012). Post-concussion syndrome has plagued a number of high-profile athletes who have endured devastating symptoms, disability, and pathologic changes mirroring those of Alzheimer's disease (Bernick et al., 2012). Notwithstanding this information and the continual expansion and evolution of MMA training facilities and participants, the research regarding the epidemiology of head injuries in this particular sport remains sparse (Bernick et al., 2012). The number of young persons fighting at the amateur/youth level continues to increase with every passing year (Hutchison et al., 2014). To prevent head trauma and protect the current and future crop of fighters of the sport it is important to comprehend the mechanism by which injury occurs and the severity of injuries associated with MMA. Yet, to date, no studies have been published that epidemiologically examine the head trauma experiences of MMA fighters.

To address this research gap, the study described in this thesis seeks to identify and quantify the factors associated with head trauma in MMA athletes, for the purpose of assisting the process of developing policy and practice that will reduce future head trauma.

Objectives

There are three objectives to this work:

1. Identify factors associated with being rendered unconscious in professional MMA fights.
2. Identify factors associated with receiving a diagnosed concussion among the fighters rendered unconscious.
3. Formulate policy recommendations for addressing head injury in MMA.

Background

The Definition of Concussion

Concussion is an injury to the brain induced by a blow to the head, face, or neck area. It may or may not involve a loss of consciousness. The biomechanical forces for which there is no known threshold, cause the brain to shift resulting in a series of neuropathological changes that may not seem evident at first. Typically the impairment of neurological function is brief and resolves without any intervention. However, there are certain cases where symptoms may come to fruition over a few hours or days. The symptoms mirror functional disturbance rather than a structural injury. For this reason abnormalities are often not seen on standard neuroimaging tests. The resolution of clinical and cognitive symptoms varies with each athlete.

Some of the signs and symptoms include: drowsiness, headaches, slured speech, bothered by light or noise, lethargy, weakness, numbness, or decreased coordination, vomiting or nausea, and unusual behavior. Often times the victim will suffer from short-term memory loss and will not recall events leading up to, or following the incident. Normal cellular function in the brain must be restored or the athlete risks suffering further cognitive deficits. Therefore, the Centre for

Disease Control and Prevention (CDC) proposes a five-step program before an athlete can return to play (Centre for Disease Control and Prevention website, 2014). One must display no concussive symptoms, begin with five to ten minutes of aerobic activity (i.e. walking, jogging), slowly increase the heart-rate over time, and eventually add heavy, non-contact physical activity. Once the athlete has had a full contact practice then he or she can resume competition (Centre for Disease Control and Prevention website, 2014).

Concussion Research in Other Sports

While the discussion of concussions is a relatively new topic in MMA circles, head trauma research has a deep history in the sport of boxing. A key finding is the importance of the level of competition and its association with the degree of head trauma. Boxers fighting at the amateur level show milder neurophysiological and neuroimaging evidence of concussions mainly due to their use of headgear, increased glove-padding, and shorter fights (Daneshvar, Nowinski, McKee, 2011). It is worth noting however, that the effectiveness of head-gear in boxing is yet to be formally tested.

Boxers spend the majority of their time in a training setting due to the importance of sparring to prepare for bouts regardless of the level of competition (Zazryn et al., 2009). The more a fighter spars the greater the likelihood of neurocognitive decline (Barry, 2009). Henceforth, a fighter does not necessarily need to be a in a competitive fight to sustain a concussion or experience cognitive impairment (Zazryn et al., 2009). The mechanical forces of the punch and how the impact is absorbed through the intracranial cavity is related to the degree of head trauma (Barry, 2009). For instance, the roundhouse or the hook are punches that deliver more force compared to the straightforward jab. Hand velocity is the primary determinant for punch-force. The force transmitted by a punch is directly proportional to the mass of the glove

and the velocity of the swing, and is inversely proportional to the total mass opposing the punch (Barry, 2009).

For this reason, the male knockout rate is significantly (five times) higher than the female knockout rate. Female boxers have a lower punching power and fight fewer rounds than their male counterparts lowering their risk of injury (Bledsoe, Guohua, Levy, 2005). The result of the bout is a pivotal variable as being knocked out doubles the risk of head trauma making concussions a rare occurrence among female fighters (Barry, 2009). Another important aspect is the gender differences in outcome once a concussion has been sustained (Frommer et al., 2011). According to the literature, males report more cognitive symptoms whereas females report neuro-behavioral symptoms (Covassin et al., 2012). Female athletes tend to report more post-injury symptoms after concussion and perform worse on visual memory compared to male athletes (Covassin et al., 2012). The theory behind this finding is associated with the stigma surrounding male athletes that consists of having to play through pain and hiding any symptoms to avoid being removed from participating. Many will choose to ignore their concussion symptoms following injury. Female athletes tend to be more concerned about their symptoms and their overall health (Covassin et al., 2012). Male sport participation has always been higher in comparison to female sport participation, but it is worth noting that participation among females has grown by 41% over the past decade. With more participation comes higher levels of sport-related concussions for which females have now surpassed males (Frommer et al., 2011).

When considering other prominent contact sports in the USA, certain variables are found that consistently play a key role in the incidence of head trauma: advancing age, the body's position at the time of the trauma, level of competition (i.e. amateur versus professional) and differences among racial/ethnic groups. For example, a study by the CDC revealed that

concussion risk is greater for black youth compared to Caucasian youth (Hunt, 2014). The younger the athlete, the longer it takes for him or her to recover from a concussion and return to the baseline of cognitive testing (Athiviraham, 2012). It takes a high school athlete 10 to 14 days to recover in comparison to a college athlete who tends to recover within a week. The opposite is true for ice hockey players due to the introduction of body-checking at the pre-teen age. Head trauma in junior hockey is a serious concern as 25.3% of players have suffered at least one concussion during their playing career by the time they graduate to the professional level (Johnson, 2011). This highlights the necessity to study the effects of head trauma on the developing brain (McBride, 2012). The previous hypothesis that children do not generate strong impact due to their light weight and lack of speed has been thwarted by recent investigation. An average of 107 impacts per player occurs during a football season with the majority of high level impacts occurring during practice sessions (McBride, 2012). Youth sports can produce high head accelerations which can lead to head trauma and greater vulnerability to suffering a second concussion in the future (McBride, 2012). Researchers presume that because children lack muscle tone, particularly in the neck and chest, their head is vulnerable to large accelerations (McBride, 2012).

American football consistently shows the highest rate of head trauma in all youth sports (Athiviraham, 2012). The majority of concussions occur at the high school level where it comprises of 8.9% to 13.2% of injuries compared to 7.9% of collegiate sport injuries. Parallels can be drawn between American football and boxing in terms of the pattern of chronic brain damage that players sustain during their career (Casson et al., 2005). The preponderance of rotational and lower translational accelerations seen in both boxing and American football lead to long-term brain injury. The majority of head injuries occur on the defensive side of the game

whether it would be ice hockey or American football. Linebackers were shown to have the highest concussion rate at 40.9% because the tackle accounts for 48% to 65% of all concussions in football (Bleakley, Tully, O'Connor, 2011).

Moreover, among the variables that may influence neurocognitive function is the difference between various racial/ethnic groups and their educational level (Teng & Manley, 2005). Socioeconomic status relates to the quality of education may represent a confounder in neurocognitive performance within and between different ethnic or racial groups. Early results implies that lower socioeconomic status is 'negatively related to neurocognitive achievement.'(Noble, Norman, Farah, 2005).

The Importance of Concussion Research in MMA

There are more questions than answers when it comes to the public health issue of head trauma in mixed martial arts. The sport has managed to attract a wide array of participants internationally by appealing to amateurs and expanding the number of training facilities. Little is known about the seriousness and mechanism of injuries in MMA, leaving the current generation of fighters unprotected by evidence-based safety policies.

According to the CDC, approximately twenty percent of athletes partaking in contact sports suffer from chronic traumatic encephalopathy (CTE) highlighting the frightening frequency of occurrence (CDC, 2015). The monumental discovery of retired, professional athletes (particularly in the National Football League) who have died with pathologically confirmed CTE has led many to panic about the lack of knowledge surrounding head injuries. Scientists do not yet understand the link between repetitive blows to the head and chronic neurodegenerative conditions. Early detection of CTE is nearly impossible due to the lack of

biological markers and scientists are not aware of the possible brain disorders related to cumulative head trauma.

Risk factors for CTE remain poorly understood, resulting in a lack of criteria for early detection and intervention. However, the long-term effects of repetitive head trauma are well documented, due to the sad experiences of many professional athletes as they age. Dementia, depression, and changes in personality are just a few of the health issues associated with multiple concussions (Fainaru-Wada & Fainaru, 2013).

By investigating the factors associated with head trauma, policies can be developed to help protect the fighter from head injury, and thus reducing the likelihood of impaired brain function later in life.

Tests to Identify Head Trauma

The need for a practical screening test to evaluate athletes who may have suffered from a concussion is important, since recognizing early signs of head trauma can improve prognosis (Fainaru-Wada & Fainaru, 2013). One of the more widely used evaluation tests for identifying head trauma is known as Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). It includes four sections: a demographic profile and health history questionnaire, current concussion symptoms and conditions, baseline and post-injury neurocognitive tests (word discrimination, symbol and color matching), and a graphic display of ImPACT test scores (impacttest.com). It is computerized and lasts twenty-five minutes. The score represents the total for the 22 symptom descriptors. A lower score indicates fewer endorsed symptoms by the test-taker. The baseline test serves as a comparison to a repeat test to assess any damage linked to the trauma (impacttest.com).

The Military Acute Concussion Evaluation (MACE) is a broad examination consisting of three components to determine if an MMA fighter has suffered head trauma. The test includes a cognitive history, memory and orientation testing, and neurologic screening (McCrea et al., 2014). The test takes approximately twenty minutes to administer and a score out of thirty is given based on the first two components. According to MACE, a score below twenty-five signifies neurocognitive impairment and requires further testing (McCrea et al., 2014).

Early detection of brain trauma may allow a fighter to cease his or her dangerous activities before damage becomes permanent. However, in truth, there is no objective way to discern whether an individual should stop fighting. But the King-Devick test or K-D test is the latest evidence-based practice that ringside physicians use to identify head trauma in MMA athletes (Galetta et al., 2011). It is the quickest, most practical cognition test in sports because it can be administered within a two minute time-frame. The individual must read a series of single-digit numbers, as quickly as possible, from left to right on test cards (Galetta et al., 2011). The test includes a demonstration card and three test cards. The sum of the three test card time scores constitute the summary score for the entire test. The number of errors while reading the test cards are recorded (Galetta et al., 2011). The test captures impairments in areas that correlate with suboptimal brain function along with eye movement and language impairments by measuring the speed of rapid number naming (Galetta et al., 2011). The combatants test results prior to the fight are compared with the results following the fight. Galetta et al, performed a cross-sectional study involving boxers and MMA athletes to analyze the effectiveness of the K-D test in comparison with the MACE. Evidence suggested that the K-D test is accurate and reliable in determining if a fighter has suffered from head trauma (Galetta et al., 2011).

Fight Dynamics

Different fighting organizations enforce different rules and regulations. The following is a summary of the dynamics of a bout for the three main MMA fighting organizations: UFC, Bellator, and OneFC (recently named One Championship).

The Ultimate Fighting Championship

The arena where the fight occurs is known as "The Octagon." The supposed purpose of the octagon shape is to eliminate any potential advantage of one martial art discipline (UFC, 2015). It is 750 square-feet and is bordered by six feet high, padded walls to prevent fighters from falling out. The ring floor contains at least an inch of foam padding (UFC, 2015). During a fight there are only three individuals present in the octagon: two fighters and a referee. Championship MMA contests are five rounds whereas non-championship contests are three rounds (UFC, 2015). Each round lasts a maximum of five minutes with a one minute rest period between each round. During each rest period corner-men and cut-men are permitted to enter the octagon (UFC, 2015).

Cut-men are employed to apply Vaseline to the areas of the face that are prone to cuts such as eyebrows and cheeks (UFC, 2015). They provide medical assistance if the fighter has incurred a cut or facial swelling. Corner-men, usually part of the athlete's training camp, provide motivation and tactical advice in between rounds. A total of two individuals can enter the octagon in between rounds to address the fighter (UFC, 2015).

Contestants can only wear gloves weighing four to six ounces and shorts approved by the commission. Shirts are prohibited in the male divisions (UFC, 2015).

The referee enforces the rules, instructs the fighters and has the ability to end the fight (UFC.ca). Prior to the fight, the referee inspects the fighter and ensures he or she is wearing a cup and mouthpiece (UFC.ca). In the event that both fighters remain standing at the end of the

bout there are three licensed judges present to score each round. The winner of the fight is determined by the judges' scores (UFC.ca).

The weight-class for each division is as follows: Straw-weight - up to 115 pounds; Flyweight - over 115 pounds to 125; Bantamweight - over 125 to 135 pounds; Women's Bantamweight - over 125 to 135 pounds; Featherweight - over 135 to 145 pounds; Lightweight - over 145 to 155 pounds; Welterweight - over 155 to 170 pounds; Middleweight - over 170 to 185 pounds; Light Heavyweight -over 185 to 205 pounds; Heavyweight - over 205 to 265 pounds; Super Heavyweight -over 265 pounds (UFC.ca).

Bellator

Bellator is an organization that follows the unified rules of MMA (Bellator website, 2015). Groin strikes, eye gouging, kicking or kneeing a grounded opponent, downward elbows, strikes to the back of the head, head butting, biting, or grabbing the fence. Upon a violation of the rules, a referee can either warn the fighter, take a point away, or disqualify the fighter depending upon the regularity and severity of the foul (Bellator website, 2015). All non-world championship fights in Bellator consist of 3 five-minute rounds. World championship fights consist of 5 five-minute rounds. All fights have a one-minute rest periods between rounds (Bellator website, 2015). Bellator follows the ten point system described in the unified rules of MMA. The winner of the round is given ten points while the losing fighter is awarded nine points or less. Weight classes are similar to those established by the UFC. Fights and fighters from Bellator were not included in the dataset for this study.

OneFC

OneFC, headquartered in Singapore, combines the unified rules of MMA and the Best Practices from Asian and non-Asian rules (OneFC website, 2015). The judging criteria and

fighting techniques allowed mirror the UFC and MMA global rule set. The bout duration guidelines are identical to that of the UFC and Bellator (OneFC website, 2015). Fights and fighters from OneFC were not included in the dataset for this study.

Reflectivity

I was inspired to study head trauma in MMA after reading an intriguing book called 'League of Denial' which exposed how the National Football League (NFL) tried to cover up the concussion epidemic in American football. I linked this great piece of investigative journalism to another sport that continues to grow in popularity – MMA. I have been an avid fan of MMA for years, but after reading 'League of Denial' I was curious whether large promotional companies like the UFC were studying the effects of this particular combat sport on the brain. After doing some digging, I found very little regarding prevalence or incidence of head trauma in MMA. I wanted to investigate the potential causes of concussion for this great sport. In my opinion, once the factors associated with head trauma are known, then the governing bodies of the sport can implement ways to protect current and future fighters from devastating head injuries. This study can lay the foundation for future research in order to better prevent, diagnose, and treat head trauma in MMA.

Methods

Binomial logistic regression analysis was used to answer two research questions: *What are the factors associated with head trauma among professional mixed martial arts (MMA) athletes?* And, *what are the factors associated with being diagnosed with a concussion among the fighters rendered unconscious?* Two datasets were employed to answer these questions, a "large dataset" and a "small dataset." The large data-set was used to address the first research question and the smaller subset of data was used to answer the second research question. The Research Ethics Board at the University of Ottawa granted ethics approval for secondary data analysis on July 7th, 2014 (see Appendix 1).

1. Data Source

Large Dataset

A data set of 14268 professional mixed martial arts fighting rounds from the professional organizations Ultimate Fighting Championship (UFC), World Extreme Cagefighting (WEC), and Strikeforce was procured from an American company called Fighmetric LLC. Fightmetric specializes in monitoring professional combat sports. The data contains variables describing the demographics of the fighters, the details of the actual fight, including total strikes, intensity of strikes, duration, submission types (especially chokes), and how the fight was resolved (knockout, submission, or by judges' decision).

The dataset contains male and female fighters and is indexed by a factor called "fight-fighter," which is the instance of a single competitor performing in a given fight (see table 3 for

variable list and description). Thus for every single fight that was monitored, two entries appear in the dataset, one for each fighter participating in the fight.

Data commencing from the universal adoption of the unified rules of MMA (see Appendix) eleven years go up until June 2014 was used in this study.

The statistical software SPSS 20 was used to analyze the data from Fightmetric. Of the 14268 rounds in the dataset only the rounds of the defeated fighter were selected and analyzed. Therefore 7134 rounds were used in the logistic regression to answer the research question: *What are the factors associated with being rendered unconscious in professional MMA fights?*

Small dataset

From the cases in the "large dataset" in which a fighter was rendered unconscious, the SPSS "random sample of cases" function was used to randomly select 300 rounds for deeper analysis. Of those 300 rounds, information was found on 265, allowing the enrichment of those rounds with additional variables.

Media sources were searched for all information pertaining to the post-fight outcome of those 265 rounds. Each case was enriched with additional variables describing further demographic characteristics of the fighter, and whether the fighter was medically diagnosed with a concussion. The additional variables created were: fighter's age, ethnicity (white vs black or African-American), gender, number of pro fights, if the fighter experienced a concussion prior to the date of the fight in the analysis, and the time since the fighter's previous fight. A subset was chosen because time and resource limitations prevented this intensive approach from being applied to the full "large dataset."

An important note to keep in mind concerning the gender variable, is that there were very few female cases in the small dataset. Very few female fights end in a knockout which explains the reason for the limited number of cases in the small dataset.

To control for the multiple testing bias that can result from using the "fight-fighter" criterion as the case index, the initial analytical plan was to create a series of cascading sub-datasets. In each sub-dataset, a fighter's name would appear only once. A regression analysis was to be applied separately to each cascade or sub-dataset. For example, if John Smith's name appeared five times among the 265 cases, his name would be included in five different regressions with his earliest (based on date) fight going in the first regression model.

However, there were very few fighters appearing more than once among the 265 cases of the "small dataset", meaning that a sub-dataset made up only of fighters' second unconsciousness experiences was too small to analyze. Therefore, the "small dataset" was pruned of all fights featuring fighters' second or later appearances in the data. Its final sample size was 231, with 34 cases discarded (see Appendix page 50).

2. Analyses

Large Dataset

Univariate Methods

The first step was to run a univariate analysis on all the variables in the 7134 entry data set. Frequencies and descriptives were run to determine the distribution of the variables and if there were any missing values or if values needed to be transformed (i.e., whether they were skewed).

The variable for weight, which initially was continuous, was transformed into a categorical variable, with category cut-offs determine by the UFC's weight class definitions. At

this stage, the dichotomous variable "ConsciousUnconscious" was imputed into the dataset. Cases in which a fighter was rendered unconscious was defined as a loss that occurred via knockout (by a strike) or technical knockout (by strikes).

Bivariate Methods

Once coding had been completed, a bivariate analysis was run to independently identify which variables were associated with being rendered unconscious. Independent sample t-tests were run for continuous variables and chi-square tables were produced for the categorical variables. The purpose of this step is to identify the variables that already demonstrate some degree of association. If a variable had a p-value of less than 0.2 it was included in the future logistic regression.

Multivariate Methods

Lastly, the logistic regression analysis was employed to model covariates against the dichotomous outcome "unconsciousness vs no unconsciousness". All categorical predictor variables were identified as such in the forced-entry logistic regression model. Various suspected interaction terms were tested, but none were found to be statistically relevant.

Diagnostics for the goodness of the regression model's fit were tested using classification plots, the Hosmer-Lemeshow test, and an examination of the casewise listing of residuals. Unadjusted and adjusted p-values were examined *post hoc,* and adjusted odds rations reported.

Small dataset

Univariate and bivariate analyses were implemented in the same manner and for the same purpose to answer the second research question: *What are the factors associated with being diagnosed with a concussion in professional MMA fights?*

The dichotomous variable “Diagnosed_Concussion” was created, derived from media reports, and served as the outcome variable for regression models applied to this dataset. Additive interaction terms for gender and weight class, age and previous concussions, and age and previous fights were also introduced into the regression model.

As fighters get older their number of professional fights increases therefore there was suspected interaction between the two variables. A multiplicative interaction term was included in the logistic regression to account for the suspected effect between the two variables. The same process was used for age and previous concussion as the likelihood of suffering head trauma in a professional fight increases with age.

Results

Large Dataset

Table 1 describes the variables included in the logistic regression analysis, which was performed to determine the factors associated with being rendered unconscious in a professional MMA fight.

If the fighter's ending position in a fight is on the ground it is negatively associated with the outcome of unconsciousness ($p<.05$; OR 0.18). Unsurprisingly, the head as an ending target is greatly associated with being rendered unconscious ($p<.05$; OR 5874.1). The more head strikes landed ($p<.05$; OR 1.5) while the recipient is on the ground, the more likely the fighter will be knocked unconscious. Interestingly, power strikes landed to the body in the clinch ($p<.05$; OR 1.5) is also associated with the outcome of unconsciousness, though, confusingly, more head strikes in general are protective against unconsciousness ($p<.05$; OR 0.5). Lastly, longer fights are associated with not being unconscious ($p<.05$; OR 0.58). The large dataset failed the Hosmer-Lemeshow test with a p-value of .116, meaning that the model is a "good fit" for its included variables.

Table 1. Variables in logistic regression analysis to determine the factors associated with being rendered unconscious in a professional MMA fight.

Variable	Unadjusted p-value (obtained from t-test or chi-square)	Adjusted p-value (obtained from logistic regression)	Odds Ratio
Ending Position	**.000**	**.012**	**.182**
Ending Target	**.000**	**.000**	**5874.133**
Ground Head Strikes Landed	**.000**	**.019**	**.500**
Ground Head Jabs Landed	**.000**	**.029**	**1.489**

Clinch Body Power Landed	**.000**	**.029**	**1.495**
Round Number	**.000**	**.000**	**.579**
Weight Class	.072	.888	.968
Ground Body Jabs Landed	.000	.554	.827
Clinch Body Jabs Landed	.000	.597	1.083
Clinch Head Power Landed	.000	.104	.594
Takedown Shots Landed	.000	.992	1.004
Head Power Landed	.000	.671	1.054
Head Jabs Landed	.010	.976	.994
Takedown Slams	.447	.756	1.199
Ground Body Strikes Landed	.000	.743	1.155
Clinch Body Strikes Landed	.000	.526	.800
Clinch Head Strikes Landed	.000	.150	1.337
Distance Body Strikes Landed	.000	.268	.479
Significant Ground Head Strikes Landed	.000	.712	1.288
Significant Clinch Body Strikes Landed	.000	.375	.676
Significant Clinch Head Strikes Landed	.000	.761	1.146

Significant Distance Body Strikes Landed	.000	.313	2.096
Significant Distance Head Strikes Landed	.135	.748	.898
Significant Ground Strikes Landed	.000	.736	1.229
Significant Clinch Strikes Landed	.016	.988	1.004
Significant Distance Strikes Landed	.000	.413	.807
Significant Body Strikes Landed	.000	.688	.884
Significant Head Strikes Landed	.000	.933	.978
Significant Strikes Landed	.105	.395	1.208
Total Strikes Landed	.001	.412	.882
Takedowns Landed	.000	.439	.836
Stand-Ups	.000	.060	.767
Advance to Back	.043	.870	1.108
Advance to Mount	.062	.141	2.667
Advance to Half-Guard	.000	.660	.803
Ground Body Power Landed	.000	.999	1.000
Ground Head Power Landed	.000	.575	.940
Clinch Head Jabs Landed	.000	.730	.970

Body Power Landed	.000	.405	.865
Body Jabs Landed	.000	.397	.846
Distance Knockdowns	.053	.143	.406
Offensive Passes	.001	.618	.830
Constant	N/A	N/A	N/A

Small dataset

Table 2 lists the variables included in the logistic regression analysis to determine the factors associated with being diagnosed with a concussion in an MMA fight, once unconsciousness has been rendered.

Increasing age is positively associated with head trauma ($p<.05$; OR 3.2). Prolonging the time period in between fights is protective against head trauma ($p<.05$; OR 0.81). A fighter who is black or African-American is also more likely to be diagnosed with a concussion than is a Caucasian fighter ($p<.05$; OR 0.16). Two variables that are protective against head trauma are: significant clinch strikes landed ($p<.05$; OR 0.02) and significant distance body strikes landed ($p<.05$; OR 0.002). The last significant variable, power strikes landed to the body at distance, is heavily associated with head trauma ($p<.05$; OR 557.373). The small dataset failed the Hosmer-Lemeshow test by yielding a p-value of .854, which suggests that the model is a "good fit" for the included variables.

Table 2. Variables in logistic regression analysis to determine the factors associated with being diagnosed with a concussion in a professional MMA fight.

Variable	Unadjusted p-value (obtained from t-test or chi-square)	Adjusted p-value (obtained from logistic regression)	Odds Ratio
Age	**.244**	**.004**	**3.189**
Time Between Previous Fight in Months	**.572**	**.003**	**.807**
African-American vs White	**.215**	**.014**	**.164**
Significant Distance Body Strikes Landed	**.486**	**.005**	**.002**
Significant Clinch Strikes Landed	**.114**	**.046**	**.024**
Body Power Landed	**.289**	**.001**	**557.373**
Age * Number of Pro Fights	N/A	.411	.978
Age * Previous Concussion	N/A	.259	1.416
Gender * Weight Class	N/A	.374	.846
Gender	.459	.173	9.305
Weight Class (Category 1) Super/Light Heavyweight	.558	.802	.835

Weight Class (Category 2) Middle/Welterweight	.558	.883	.879
Number of Professional Fights	.000	.224	2.527
Previous Concussion	.000	.280	.000
Ground Body Jabs Landed	.414	.737	1.854
Clinch Body Jabs Landed	.049	.489	2.639
Head Power Landed	.013	.643	.509
Head Jabs Landed	.003	.882	.868
Ground Head Strikes Landed	.453	.123	247.482
Clinch Body Strikes Landed	.021	.228	15.976
Clinch Head Strikes Landed	.229	.638	.406
Significant Clinch Body Strikes Landed	.069	.946	.847
Significant Clinch Head Strikes Landed	.094	.235	8.094

Significant Distance Head Strikes Landed	.005	.693	2.377
Significant Ground Strikes Landed	.391	.958	.886
Significant Distance Strikes Landed	.011	.997	1.006
Significant Body Strikes Landed	.073	.929	1.086
Significant Head Strikes Landed	.376	.689	.693
Significant Strikes Landed	.992	.295	5.202
Total Strikes Landed	.356	.788	.668
Takedowns Landed	.163	.937	1.129
Stand-Ups	.457	.469	2.439
Ground Head Jabs Landed	.353	.098	.006
Clinch Head Jabs Landed	.237	.699	.587
Round Number	.744	.530	.749

Constant	N/A	N/A	N/A

Discussion

The incidence of knockouts or technical knockouts in professional MMA identified in this study is 23%, which is much higher than the previously reported rates of 6.4 per 100 Athletic Exposures (AE) and 4.8 per 100 AEs (Buse, 2006; Hutchison, 2014). The head representing the ending target was a clear factor associated with being rendered unconscious. Hutchison et al (2014) reported a mechanism associated with knockouts via contact between fist and mandibular, maxillary, or temporal regions of the head. The fighter's positioning when receiving strikes in the octagon is also a key factor in determining consciousness. Being on the receiving end of jabs or strikes in the clinch or on the ground increases the fighter's vulnerability to losing consciousness. The theory supporting this finding is that when the losing fighter is on the ground he is forced to absorb blows to the head and body regardless of his attempt to protect himself. These factors are linked to the duration of the fight. The longer the fight lasts the more fatigued the fighters get, elevating the likelihood having to incur damage to the head and body. This association opposes the finding attained in a previous study where the greatest risk of sustaining a knockout or technical knockout was during the first minute of a round, and in the first round of a fight (Hutchison et al., 2014). On the contrary, this study suggests that fighters lose consciousness in the later rounds of a fight.

Furthermore, strikes from distance are not influential in predicting concussion. When a fighter is on his feet he can better guard himself from strikes and has ample time to react to his opponent. Interestingly, power strikes landed to the body at distance plays a strong role in being diagnosed with a concussion in an MMA fight. Previous literature has not examined the influence of body strikes, and it is unclear what the mechanism of trauma might be. One can hypothesize that damage to the body is inevitable if the combatant finds himself in a vulnerable

position. Perhaps this would weaken the fighter and leave his head further exposed to potential damage.

In addition, the age at which a fighter steps into the octagon is associated with head trauma. The older the fighter, the more likely he or she is to suffer a concussion. In support of this finding, Jordan et al (1992) performed computed tomography (CT) scans on 338 active professional boxers. 68% of those who reported abnormal CT scans had previously suffered a KO or TKO. All were slightly older than those with normal CT scans and a history of KO (Jordan et al., 1992). Lin et al (2006) studied the effects of age on 291 Olympic Taekwondo athletes and discovered similar findings. However, many authors suggest that fighting skills increase with age and those with lower anaerobic and aerobic capacities will struggle to compensate with skill or experience. This signifies that the level of competition may be an important element in the age effect (Albuquerque et al., 2012). Other researchers suggest that the effect of age exists in sports that value physical characteristics such as weight, height and strength (Delorme et al., 2010). In contrast, several studies suggest that the cut-off criteria of weight and belt (level of competition) mitigates the disadvantages to younger fighters and makes the age effect negligible (Albuquerque et al., 2012).

Moreover, the number of months in between a combatants fights is detrimental to the discussion of concussion in MMA. The more time, in months, the fighters spend resting or training prior to their next fight the less chance they will suffer a concussion during the fight. Strong evidence is lacking to identify an appropriate time-frame that fighters should adhere to before initiating training for their next fight. The International Conference on Concussion in Sports suggests cognitive rest and avoiding any activity involving attention, memory, concentration and reasoning to hasten recovery (Gibson et al., 2013). A single-centre

retrospective cohort study of 184 athletes performed by Gibson et al (2013) showed slight association between cognitive rest and the duration of the athlete's symptoms during the univariate analysis. This association did not last after including other variables in the analysis. High levels of physical and cognitive activity following head trauma may hinder recovery (Majerske et al., 2008).

The ethnicity factor suggests an intriguing role in head trauma in MMA. According to this study, a black or African-American fighter has a higher association with head trauma than does a Caucasian fighter. Researchers propose that education and reading level are factors that influence neurocognitive performance among different ethnic groups (Teng & Manly, 2005). Education is protective against cognitive deficits following various forms of brain injury as fighters with a high school education or less show more associations between fight exposure and cognitive test scores (Banks et al., 2013). However, this study did not include these two variables. It has been noted that the quality of education plays a significant confounding role in the neurocognitive performances among the various racial or ethnic groups (Manly et al., 2002). Lower socio-economic status is also negatively correlated with neurocognitive achievement (Noble, Norman & Farah, 2005). Kontos and his colleagues (2010) performed a prospective case–control design that was used to compare the neurocognitive performance and symptoms between White and African-American athletes at baseline and 2- and 7-day post-concussion. ImPACT was used to evaluate neurocognitive function. Results showed that there were no significant differences in computerized neurocognitive performance and increased symptoms (verbal memory, visual memory, reaction time, and total reported symptoms) following a concussion between Whites and African-Americans (Kontos, Elbin, Covassin, Larson, 2010).

Another element that may be linked to the ethnicity result is the fact that race might be a proxy for nationality. The ethnicity variable was coded as 1 being "white" and 2 being "black or African American." Black fighters were born and raised in various countries around the world where training styles can be much more vigorous and intense. Different MMA gyms have different philosophies and training regimens which are reflected in the fighters they produce. For instance, Brazilian fighters are known for their jiu-jitsu prowess, while Latino fighters are known for their boxing ability. It is possible that ethnicity could be a confounding variable.

Policy Interventions

As it stands, title matches are sanctioned for five rounds and non-title matches are three rounds. There is a one-minute rest period in between rounds. Based on the factors associated with being rendered unconscious in this study, match lengths might be too long. It is advisable that each match should last a maximum of three rounds and more time should be added in between rounds to decrease levels of fatigue. It is further advisable to not only increase time in between rounds of a match, but to have a rest period of at least three months in between fights. A criteria should be established based on the fighter's injuries following a fight to determine when he or she is eligible to fight again, but a minimum rest period of three months should be made mandatory. Age is also heavily significant with concussion in this study therefore an advisable retirement age should be set by MMA fighting organizations.

It might be worth exploring whether different performance requirements can be mandated for older fighters, with those of advanced age placed in shorter duration fights. More investigation is required to determine what age constitutes "older", however.

In MMA, KOs and TKOs are rewarded via financial compensation (i.e. "knockout of the night") making it difficult to suggest potential safeguards to reduce the number of concussions in

the sport. According to Hutchison et al (2014) there is an average of 2.6 strikes to the head after a KO. Evidently, fighters need more protection after suspected loss of consciousness by the arbiter of the match. In agreement with the Hutchison et al (2014) study, referees should be trained to realize a fighter's loss of consciousness and halt the match instantly. In boxing, there is a ten second window after a fighter has been knocked down to allow for a quick evaluation of possible head injury before the match is resumed. A similar rule should be applied to MMA to reduce rates of concussion.

Following a fight, athletes are evaluated by on-site medical staff and a medical suspension is given to the fighter to ensure appropriate recovery time (Hutchison et al., 2014). Often times, fighters return to training prematurely as the suspension is heavily reinforced. Brain-imaging for those who lost consciousness during the fight should be made mandatory.

An additional policy direction is gear-based. Amateur boxers benefit from head protection, and there is no reason that such gear could not also find a role in MMA, though modifications would have to be made to allow for chokes and other advanced ground positions. As well, MMA gloves are thinner than boxing gloves, allowing for greater and harder impact. This is necessary to keep the fingers free to explore submission holds. However, an engineering challenge can be presented to develop a thicker glove and allows sufficient mobility for MMA purposes.

Limitations

The data used for the analysis are intensive, but may be missing potential significant variables (i.e. education, socio-economic status) that may alter the results found. The results yielded for the 231 fighters randomly selected for the subset to determine the factors associated with diagnosed concussion may be down an anomaly of fights. Perhaps, if other fights had been

selected the results would have been different. Also, this study only included fighters who were defeated in the octagon. However, it is plausible that the winner of a professional MMA fight may also suffer head trauma. The data only included professional fights, therefore excluding information on sparring sessions and fighter's experience at the amateur level. A recent study has shown that KOs in MMA are related to microstructural damage in the brain (Shin et al., 2013). Rates of head trauma among amateurs is expected to rise due to the rapid growth of the sport (Hutchison et al., 2014). At that level of competition, young fighters do not have the same access to medical attention as professionals. Uniform policies across all jurisdictions should be put in place by medical authorities to ensure that all athletes who have experienced a KO or TKO receive the appropriate medical care (Hutchison et al., 2014). Moreover, this study did not measure the fighters' participation in other sports. It is possible that these fighters had sustained concussions while taking part in other sports besides MMA. For instance, a former MMA fighter by the name of Brock Lesnar was a professional wrestler for the World Wrestling Entertainment (WWE) prior to transitioning to MMA. He also had a brief stint in the National Football League with the Minnesota Vikings despite not having played competitive football since his high school years. This is a clear example of a professional athlete who may have suffered from head trauma before becoming a professional MMA fighter. This research did not take into account any sport or event that may have increased a fighter's susceptibility to concussions prior to reaching the professional MMA level.

In accordance with the Hutchison study, a "uniform cross-jurisdictional database" that records KOs and TKOs for all fighters should be created to prevent premature return to the sport. Further investigation is needed to ascertain the effects of head trauma at the amateur level and how it influences a fighter's professional career.

Future Research

There are a vast number of definitions for head trauma or concussion. The scientific community needs to come to a consensus on a definition in order to make strides in diagnosis and treatment of this medical condition. Based on a definitive explanation of head trauma research can be performed to establish a criteria to evaluate athletes. Further research needs to be done to evaluate the efficacy of the K-D test used by ringside physicians to detect head trauma. Providing solid evidence with regards to the efficacy of this diagnostic tool will set a standard for medical authorities and raise awareness for key signs and symptoms of brain insult. Little is known about the prognosis of this condition. To date, every athlete's experience varies depending on the symptoms exhibited. There is no "cure" or proven medical treatment apart from rest. The Professional Fighters Brain Health Study by Bernick et al (2012) will look to determine the relationships between measures of head trauma exposure and other potential changes in brain imaging and neurological behavioural function over time. This study will help predict early and progressive changes in brain structure and function which can lead to better treatment options in the future.

Research needs to be performed on the effects of sparring on the brain. Every MMA athlete partakes in sparring to prepare for the fight. This type of training is necessary but may cause brain injury and have other long-term health consequences. Fighters need to be evaluated at the amateur level through to their professional graduation to determine any changes in cognitive functioning. These two factors (sparring, amateur level of fighting) which are not part of this study need to be researched to better comprehend when the head trauma may be occurring and to implement procedures to protect fighters at every stage of their training.

Research on sparring would yield results on the usefulness of protective headgear in the fight to protect combatants from brain injury. A Canadian study on athletes' attitudes towards head-gear shows that many, although realizing that it may protect against head injury, do not wish to wear headgear due to lack of comfort and affordability. Few (27%) reported wearing headgear and even fewer (24%) felt that it should be made mandatory (Pettersen & Jacqueline, 2002). This attitude towards headgear would likely be reflected in MMA, but fighters should be made aware of research to support the importance of headgear in protecting against concussion. A team of researchers in Cleveland used a crash test dummy and pendulum to duplicate hook punches to the head (Bartsch et al., 2012). Five configurations of padding were analyzed including headgear with gloves, and no headgear or light gloves seen in MMA. Linear (straight-on impact) and rotational impacts which are akin to blows targeting the head causing rotation of the neck, were measured (Bartsch et al., 2012). They found that full padding, including gloves, offered the best protection against linear impacts. However, little protection was offered against rotational impacts regardless of padding (Bartsch et al., 2012). Fighters without headgear accumulate hits at a faster rate than fighter who wear head protection. During sparring sessions there's a tendency to avoid using headgear as it gets in the way of peripheral vision. Fighters should worry more about their head than their range of vision during training. Future research should look at ways to minimize rotational impact using headgear and breakdown the more or less likely sources of concussion in MMA (Bartsch et al., 2012).

Lastly, mouth-guards are mandatory in MMA, but researchers should investigate the efficacy of this piece of equipment in preventing or reducing concussions. Studies in the past have suggested that mouth-guards can lower the risk of concussion because they help absorb shock, stabilize the head and neck and limit movement caused by a direct hit to the jaw (Winters

& DeMont, 2014). A systematic review performed by Knapik et al (2007) showed that no particular material used in present-day mouth-guards is superior to another in terms of shock-absorbing capabilities. Compared with no mouth-guard this protective tool reduces the number of orofacial injuries and head accelerations. The ideal strategy to decrease the probability of head trauma is to customize the mouth-piece. A study performed on high-school football athletes showed that customizing the mouth-guard reduced the rate of head trauma by 4.7% (Winters & DeMont, 2014). It is clear that more research needs to be done to improve mouth-guards and their efficacy in protecting the brain.

MMA & Drugs

In early 2015, MMA's largest fighting company, UFC, under the leadership of the U.S. Anti-Doping Agency (USADA), implemented new drug-testing policies aimed at trying to reduce the number of positive drug tests among fighters (Erickson, 2015). According to the UFC, during 2013-14, 900 in-competition (time period between six hours prior to weigh-ins until six hours immediately following the bout) drug tests were given to competitors with 10 athletes testing positive for recreational drugs and 12 for performance-enhancing drugs (Erickson, 2015). As of July 1st, 2015, all 585 fighters in the UFC will be subject to random urine and blood testing for performance-enhancing drugs. Individual penalties are awarded by the individual state commissions, but the new protocol could see fighters sit out for years through suspension (Erickson, 2015). Millions of dollars will be invested towards in-ad out-of-competition testing. Prior to July 2015, the penalty for testing positive was generally a six to nine month ban which included a fine (Erickson, 2015). Now, the first offense for testing positive for "non-specified substances" such as anabolic steroids, growth hormones, peptides, blood doping drugs and methods is a two year suspension (Al-Shatti, 2015). With every offence the sanction gets

doubled. “Specified substances” include all recreational drugs (i.e., marijuana, cocaine) with the first offence leading to a one year suspension (Al-Shatti, 2015). Similarly, all subsequent offences will be doubled. Violations of these new rules will lead to disqualification and the forfeit of title, ranking and compensation (Al-Shatti, 2015). The new drug testing protocol will likely see each fighter get randomly tested five times during the upcoming year. All testing will be overseen globally by the World Anti-Doping Agency (WADA) (Al-Shatti, 2015).

Recently, the UFC has decided to ban intravenous use for rehydration following weigh-ins (Fowlkes, 2015). Fighters often weigh-in after days of fasting and dehydration in order to fight at a certain weight. After stepping on the scale they intravenously rehydrate using sodium chloride (Fowlkes, 2015). As of October 1st, 2015, this practice will become prohibited under UFC regulations. This news can impact the prevalence of head trauma in the future. Perhaps, up to this point in time, fighters that enter the octagon dehydrated are more susceptible to suffering head trauma due to their weaker state. With inhibited agility and awareness that comes with fasting and dehydrating, it is easy to speculate how fighting with low energy can increase the risk of being knocked unconscious.

Little is known about the association between recreational or performance-enhancing drugs (PEDs) and the potential positive or negative effect on head trauma (Clark & Choutka, 2011). Dr. Joseph Clark from the University of Cincinnati suggests that avoiding the use of PEDs can lower the incidence of CTE (Clark & Choutka, 2011). Combining steroid use and vigorous exercise routines will trigger muscle growth leading to larger and stronger muscles. More research needs to be performed to investigate a possible association between PED use and head trauma and if there’s increased incidence of CTE because of drug abuse (Clark & Choutka, 2011).

Conclusion

As MMA continues its exponential growth worldwide it is imperative to continue to study its effects on the brain. The investigation of the mechanism and source of injury along with the alterations that occur to the brain need to be made for the protection of current and future fighters. This study suggests that the Black or African-American population is more at risk of being diagnosed with concussion than other fighting populations. Also, the strikes to the body are just as influential as the strikes to the head creating the need for further investigation into the relationship between body shots and head injury. The fighter's positioning is also a determinant in the extent of injury in the octagon. Age is a key factor that is associated with concussion while previous concussion, surprisingly, did not play a significant role in this study.

This study concurs with the policy regulations suggested by Hutchison et al (2014) with regards to referees, rest periods, and medical treatment following a match. Referees need better training to be able to recognize the pattern of strikes that lead loss of consciousness and must stop the match as soon as a fighter is unable to defend his or her self. When a fighter is knocked down they should be awarded a timeframe where no follow-up strikes by the opposition can be delivered. Rest periods should be increased in between rounds to lower levels of fatigue and check for any signs or symptoms of head trauma. Fights should be limited to three rounds regardless of level of competition and brain imaging following a loss of consciousness should be made mandatory to enforce assessment of the fighter's condition.

Many avenues of research need to be explored with regards to head trauma in MMA. The criteria and ringside testing for medical diagnosis need to be further improved and studied. The efficacy of equipment such as headgear and mouth-guards needs to be evaluated for potential use

during competitive matches. Future research is imperative for the continual growth and health of the sport.

In summation, MMA's prosperity is closely tied to the health of the fighters that have helped make the sport prominent and successful. This study can create awareness for certain fighting populations and combat techniques that may increase risk of head trauma. Concussions are a serious medical issue that influence that lives of many athletes. It can alter, not only career paths, but the very identity of a human being. Future policies should prioritize protection of the head and demonstrate concern via the formulation of regulations to protect athletes. By identifying the factors associated with a diagnosed concussion MMA will be made safer for fighters of all ages and levels of competition.

Tables

Table 3. List of variables for logistic regression to determine the factors associated with being rendered unconscious in a professional MMA fight.

Variable	Description
V01	Round Index
V02	Round Number
V03	Fight ID
V04	Fighter ID
V05	Event Name
V06	Organization ID
V07	Event Date
V08	Fight Display Order
V09	Fight End Notes
V10	Fight Ending Time
V11	Accolade Description
V12	Weight Class ID
V13	Catchweight
V14	Fighter Name
V15	Fight Fighter ID
V16	Offensive Passes
V17	Distance Knockdowns
V18	Body Jabs Landed
V19	Body Power Landed
V20	Clinch Head Jabs Landed
V21	Clinch Body Power Landed
V22	Ground Head Jabs Landed
V23	Ground Head Power Landed
V24	Ground Body Power Landed
V25	Advance to Half Guard
V26	Advance to Mount
V27	Advance to Back
V28	Stand-Ups
V29	Fight Ending Round
V30	Fight Outcome
V31	Takedowns Landed
V32	Total Strikes Landed
V33	Significant Strikes Landed
V34	Significant Head Strikes Landed
V35	Significant Body Strikes Landed
V36	Significant Distance Strikes Landed
V37	Significant Clinch Strikes Landed
V38	Significant Ground Strikes Landed
V39	Significant Distance Head Strikes Landed
V40	Significant Distance Body Strikes Landed

V41	Significant Clinch Head Strikes Landed
V42	Significant Clinch Body Strikes Landed
V43	Significant Ground Head Strikes Landed
V44	Total Distance Head Strikes Landed
V45	Total Distance Body Strikes Landed
V46	Total Clinch Head Strikes Landed
V47	Total Clinch Body Strikes Landed
V48	Total Ground Head Strikes Landed
V49	Total Ground Body Strikes Landed
V50	Takedown Slams
V51	Head Jabs Landed
V52	Head Power Landed
V53	Takedown Shots Landed
V54	Clinch Head Power Landed
V55	Clinch Body Jabs Landed
V56	Ground Body Jabs Landed
V57	Ending Target
V58	Ending Position
V59	Ending Strike Description
V60	Fight Submission Description
V61	Conscious or Unconscious
V62	Fight Method

Table 4. List of variables for logistic regression to determine the factors associated with being diagnosed with a concussion in a professional MMA fight.

Variable	**Description**
V01	Round Index
V02	Round Number
V03	Fight ID
V04	Fighter ID
V05	Event Name
V06	Organization ID
V07	Event Date
V08	Fight Display Order
V09	Fight Method
V10	Ending Target Description
V11	Fight Ending Round Number
V12	Fight Ending Time
V13	Weight Class ID
V14	Catchweight
V15	Fighter Name
V16	Diagnosed Concussion
V17	Gender
V18	Age

V19	Number of Pro Fights
V20	Ethnicity
V21	Previous Concussion
V22	Time Between Previous Fight in Months
V23	Fight Fighter ID
V24	Ending Strike Description
V25	Ending Position Description
V26	Total Strikes Landed
V27	Significant Strikes Landed
V28	Significant Head Strikes Landed
V29	Significant Body Strikes Landed
V30	Significant Distance Strikes Landed
V31	Significant Clinch Strikes Landed
V32	Significant Ground Strikes Landed
V33	Significant Distance Head Strikes Landed
V34	Significant Distance Body Strikes Landed
V35	Significant Clinch Head Strikes Landed
V36	Significant Clinch Body Strikes Landed
V37	Significant Ground Head Strikes Landed
V38	Total Distance Head Strikes Landed
V39	Total Distance Body Strikes Landed
V40	Total Clinch Head Strikes Landed
V41	Total Clinch Body Strikes Landed
V42	Total Ground Head Strikes Landed
V43	Head Jabs Landed
V44	Head Power Landed
V45	Body Power Landed
V46	Takedowns Landed
V47	Offensive Passes
V48	Clinch Head Jabs Landed
V49	Clinch Head Power Landed
V50	Clinch Body Jabs Landed
V51	Clinch Body Power Landed
V52	Ground Head Jabs Landed
V53	Ground Head Power Landed
V54	Ground Body Jabs Landed
V55	Stand-Ups

Appendix

Unified Rules and Regulations of MMA

All MMA fights are judged by three officials who evaluate the bout from different areas around the fighting area (UFC, 2015). A 10-point system is used to determine the winner of each round. 10 points is given to the winner of the round, and nine points or less is awarded to the loser of the round. However, an even round can be scored as 10-10. Judges base their evaluations on the effectiveness of the fighters' MMA techniques and the fighter's ability to dictate the pace, location and position of the fight. The number of legal strikes and legal takedowns landed are key factors in determining the winner of the round. Judges also take into account the amount of time a fighter has been standing or on the ground to evaluate the effectiveness of the grappling or striking (UFC, 2015).

The referee is the only individual with the authority to end a bout (UFC, 2015). He may take advice from the ringside physician with regards to the decision to end a fight, but the referee and ringside physician are the only personnel that are authorized to enter the fighting area at any time during competition. There are a number of acts that are considered fouls in MMA and can result in penalties at the referee's discretion (UFC, 2015):

i. Butting with the head

ii. Eye gouging of any kind

iii. Biting

iv. Spitting at an opponent

v. Hair pulling

vi. Fish hooking

vii. Groin attacks of any kind

viii. Putting a finger into any orifice or any cut or laceration of an opponent

ix. Small joint manipulation

x. Striking downward using the point of the elbow

xi. Striking to the spine or the back of the head

xii. Kicking to the kidney with a heel

xiii. Throat strikes of any kind, including, without limitation, grabbing the trachea

xiv. Clawing, pinching or twisting the flesh

xv. Grabbing the clavicle

xvi. Kicking the head of a grounded opponent

xvii. Kneeing the head of a grounded opponent

xviii. Stomping a grounded opponent

xix. Holding the fence

xx. Holding the shorts or gloves of an opponent

xxi. Using abusive language in fenced ring/fighting area

xxii. Engaging in any unsportsmanlike conduct that causes injury to an opponent

xxiii. Attacking an opponent on or during the break

xxiv. Attacking an opponent who is under the care of the referee

xxv. Attacking an opponent after the bell has sounded the end of the round

xxvi. Timidity, including, without limitation, avoiding contact with an opponent, intentionally or consistently dropping the mouthpiece or faking an injury

xxvii. Throwing opponent out of ring/fighting area

xxviii. Flagrantly disregarding the instructions of the referee

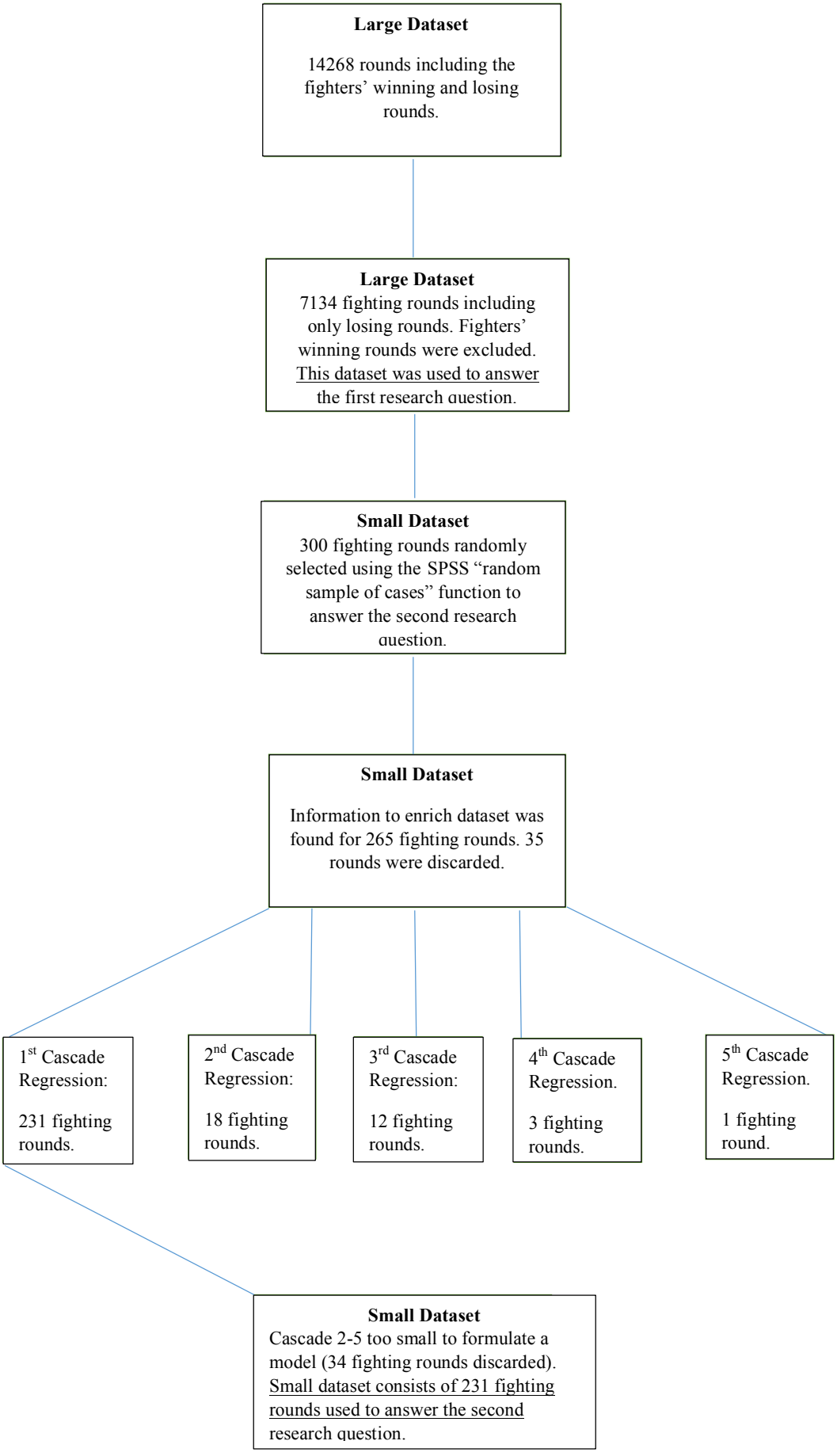
xxix. Spiking an opponent to the canvas on his head or neck

xxx. Interference by the corner

xxxi. Applying any foreign substance to the hair or body to gain an advantage

If the referee determines that an intentional foul was committed thus injuring the opponent, the accused will lose the fight via disqualification (UFC, 2015). If the bout is allowed to continue by the referee despite the foul, then the fighter who committed the foul will be deducted points. If an injury occurs, through legal means, that is serious enough to end the fight the injured contestant will lose the bout by technical knockout (UFC, 2015).

All MMA athletes must wear a mouthpiece during a fight (UFC, 2015). Male MMA athletes are allowed to wear groin protectors during competition. Female fighters can wear a chest protector. Gloves cannot weigh more than six ounces. All fighters must wear shorts approved by the commission and no shoes or feet-padding can be worn in the fighting area (UFC, 2015).


Large Dataset
14268 rounds including the fighters' winning and losing rounds.
Large Dataset
7134 fighting rounds including only losing rounds. Fighters' winning rounds were excluded. This dataset was used to answer the first research question.
Small Dataset
300 fighting rounds randomly selected using the SPSS "random sample of cases" function to answer the second research question.
Small Dataset
Information to enrich dataset was found for 265 fighting rounds. 35 rounds were discarded.
1st Cascade Regression:
231 fighting rounds.
2nd Cascade Regression:
18 fighting rounds.
3rd Cascade Regression:
12 fighting rounds.
4th Cascade Regression.
3 fighting rounds.
5th Cascade Regression.
1 fighting round.
Small Dataset
Cascade 2-5 too small to formulate a model (34 fighting rounds discarded). Small dataset consists of 231 fighting rounds used to answer the second research question.

The following is a step-by-step description of the model-building process to answer the research questions pertaining to the possible relationship between the covariates and the outcome.

Table 5.1 Summary of model parameters for each research question

Research Question	Data-Set Used	Sample Size: -Entry -Final	Inclusion Criteria	Primary Explanatory Variable	Goodness of Fit
What factors are associated with being rendered unconscious in a professional MMA fight?	Large	-14268 -7134	All fighters who lost the bout.	Conscious or Unconscious.	Adequate
What factors are associated with being diagnosed with a concussion among the fighters rendered unconscious?	Small	-265 -231	Randomly selected subset of fighters rendered unconscious.	Diagnosed with Concussion or Not.	Adequate

Table 5.2 Summary of Significant Findings for each Research Question

Research Question	Significant Covariates	Odds Ratio (95% CI)
What factors are associated with being rendered unconscious in a professional MMA fight? (Large Dataset)	Ending Position Ending Target Ground Head Strikes Landed Ground Head Jabs Landed Clinch Body Power Landed Round Number	0.182 (0.05, 0.7) 5874.133 (1734.2, 19897.4) 0.500 (0.3, 0.9) 1.489 (1.0, 2.1) 1.495 (1.0, 2.1) 0.579 (0.5, 0.7)
What factors are associated with being diagnosed with a concussion among the fighters rendered unconscious? (Small Dataset)	Age Time b/n Prev. Fight in Months Ethnicity Sign. Distance Body Strikes Landed	3.189 (1.4, 7.1) 0.807 (0.7, 0.9) 0.164 (0.04, 0.7) 0.002 (0.0, 0.15)

	Sign. Clinch Strikes Landed Body Power Landed	0.024 (0.001, 0.9) 557.373 (11.4, 27216.1)

Each analytical presentation below is grouped into the following sections. Asterisked variables represent covariates that are considered sufficiently significant to stay in the model.

1. Univariate Analysis

Frequencies for all variables in the data-set were yielded to determine the distribution of the variables, the presence of any missing values, and how to potentially code variables from text to numerical value.

Table 5.3 *What are the factors associated with being rendered unconscious in professional MMA fights?*

Variable	N	Missing Values	Mean	Standard Deviation	Kurtosis	Skewness
Fight Submission Description	7134	0	0.23	0.54	4.00	2.26
Ending Strike Description	7134	0	0.28	0.56	2.37	1.85
Ending Position	7134	0	1.32	1.91	-0.054	1.16
Ending Target	7134	0	0.24	0.46	1.66	1.64
Ground Body Jabs Landed	7134	0	0.39	0.74	0.54	1.52
Clinch Body Jabs Landed	7134	0	0.48	0.95	1.92	1.84
Clinch Head Power Landed	7134	0	0.49	0.75	-0.273	1.16
Takedown Shots Landed	7134	0	0.08	0.28	6.95	2.99
Head Power Landed	7134	0	1.29	1.23	-1.50	0.31
Head Jabs Landed	7134	0	0.74	0.74	-1.1	0.455
Takedown Slams	7134	0	0.03	0.165	30.9	5.735
Total Ground Body Strikes Landed	7134	0	0.31	0.58	1.835	1.71
Total Ground Head Strikes Landed	7134	0	0.76	0.814	-1.34	4.68

Total Clinch Body Strikes Landed	7134	0	0.53	0.64	-0.386	0.815
Total Clinch Head Strikes Landed	7134	0	0.76	0.88	-1.55	0.478
Total Distance Body Strikes Landed	7134	0	0.45	0.498	-1.96	0.194
Total Distance Head Strikes Landed	7134	0	1.00	0.694	-0.92	0.001
Significant Clinch Body Strikes Landed	7134	0	0.36	0.48	-1.67	0.579
Significant Clinch Head Strikes Landed	7134	0	0.35	0.517	0.01	1.065
Significant Distance Body Strikes Landed	7134	0	0.48	0.559	-0.684	0.606
Significant Distance Head Strikes Landed	7134	0	1.00	0.694	-0.921	0.001
Significant Ground Strikes Landed	7134	0	0.29	0.542	1.902	1.686
Significant Clinch Strikes Landed	7134	0	0.63	0.653	-0.681	0.550
Significant Distance Strikes Landed	7134	0	1.29	0.686	-0.848	-0.435
Significant Body Strikes Landed	7134	0	0.74	0.609	-0.583	0.206
Significant Head Strikes Landed	7134	0	1.35	0.90	-0.565	0.436
Significant Strikes Landed	7134	0	2.05	1.216	-1.044	0.306
Total Strikes Landed	7134	0	3.02	1.549	-1.281	-0.080
Takedowns Landed	7134	0	0.29	0.566	2.277	1.827
Stand-Ups	7134	0	0.43	0.66	0.312	1.26
Advance to Back	7134	0	0.04	0.184	23.59	5.06
Advance to Mount	7134	0	0.02	0.147	40.204	6.496
Advance to Half-Guard	7134	0	0.1	0.335	13.86	3.68
Ground Body Power Landed	7134	0	0.08	0.358	19.928	4.53
Ground Head Power Landed	7134	0	0.66	1.764	15.705	3.765
Ground Head Jabs Landed	7134	0	1.05	1.357	-0.089	1.107
Clinch Body Power Landed	7134	0	0.66	1.014	0.402	1.34
Clinch Head Jabs Landed	7134	0	0.78	1.547	4.206	2.247
Body Power Landed	7134	0	0.62	0.957	0.749	1.404
Body Jabs Landed	7134	0	0.30	0.699	5.856	2.524

Distance Knockdowns	7134	0	0.02	0.150	38.551	6.367
Offensive Passes	7134	0	0.21	0.574	9.216	3.019
Catchweight	7134	0	0.01	0.106	83.145	9.226
Weight Class	7134	0	2.28	0.841	-0.13	0.87
Round Number	7134	0	1.84	0.91	0.328	0.865

Table 5.4 *What are the factors associated with being diagnosed with a concussion among the fighters rendered unconscious?*

Variable	N	Missing Values	Mean	Standard Deviation	Kurtosis	Skewness
Ending Strike Description	7134	0	1.22	0.413	-0.08	1.386
Ending Position	7134	0	1.28	0.451	-1.051	0.979
Ground Body Jabs Landed	7134	0	0.09	0.288	6.261	2.865
Clinch Body Jabs Landed	7134	0	0.16	0.372	1.33	1.822
Clinch Head Power Landed	7134	0	0.25	0.435	-0.671	1.156
Head Power Landed	7134	0	0.48	0.501	-2.011	0.078
Head Jabs Landed	7134	0	0.37	0.484	-1.732	0.532
Total Ground Head Strikes Landed	7134	0	0.19	0.397	0.410	1.551
Total Clinch Body Strikes Landed	7134	0	0.34	0.474	-1.536	0.691
Total Clinch Head Strikes Landed	7134	0	0.31	0.462	-1.305	0.840
Total Distance Body Strikes Landed	7134	0	0.30	0.461	-1.267	0.863
Total Distance Head Strikes Landed	7134	0	0.58	0.494	-1.898	-0.345
Significant Clinch Body Strikes Landed	7134	0	0.29	0.453	-1.098	0.955
Significant Clinch Head Strikes Landed	7134	0	0.25	0.435	-0.671	1.156
Significant Distance Body Strikes Landed	7134	0	0.30	0.461	-1.267	0.863
Significant Distance Head Strikes Landed	7134	0	0.58	0.494	-1.898	-0.345
Significant Ground Head Strikes Landed	7134	0	0.07	0.254	9.747	3.415

Significant Ground Strikes Landed	7134	0	0.08	0.269	8.118	3.170
Significant Clinch Strikes Landed	7134	0	0.39	0.490	-1.825	0.437
Significant Distance Strikes Landed	7134	0	0.77	0.419	-0.247	-1.325
Significant Body Strikes Landed	7134	0	0.76	0.851	-1.448	0.487
Significant Head Strikes Landed	7134	0	1.05	0.832	-1.552	-0.098
Significant Strikes Landed	7134	0	1.20	0.664	-0.765	-0.252
Total Strikes Landed	7134	0	1.34	0.684	-0.772	-0.547
Takedowns Landed	7134	0	0.10	0.294	5.755	2.776
Stand-Ups	7134	0	0.15	0.359	1.844	1.957
Ground Head Power Landed	7134	0	0.07	0.254	9.747	3.415
Ground Head Jabs Landed	7134	0	0.17	0.379	1.032	1.739
Clinch Body Power Landed	7134	0	0.29	0.453	-1.098	0.955
Clinch Head Jabs Landed	7134	0	0.19	0.390	0.640	1.623
Body Power Landed	7134	0	0.25	0.432	-0.607	1.183
Offensive Passes	7134	0	0.05	0.222	14.646	4.064
Catchweight	7134	0	0.02	0.146	42.155	6.617
Weight Class	7134	0	1.88	0.791	-1.370	0.211
Round Number	7134	0	1.48	0.739	2.353	1.551
Ethnicity	7134	0	1.39	0.49	-1.825	0.437
Age	7134	0	29.51	4.620	-0.019	0.169
Previous Concussion	7134	0	0.52	0.501	-2.014	-0.061
Number of Pro Fights	7134	0	17.16	10.126	1.356	1.111
Time b/n Previous Fight in Months	7134	0	6.06	4.556	10.329	2.683
Diagnosed Concussion	7134	0	0.66	0.474	-1.536	-0.691

2. Bivariate Analysis

All variables considered for the logistic regression model were further investigated in this section. Variables that showed some degree of association with the outcome (p-value of ≤0.2) were considered eligible for entry into the logistic regression.

A. Dichotomous and Continuous Variables

Independent sample t-tests were performed on all dichotomous or continuous variables in the data-set. The outcome variable was selected as the grouping variable and all dichotomous or continuous covariates were grouped under the test variable.

Table 5.5 Independent sample t-tests for variables in the data-set used to determine the factors associated with being rendered unconscious in professional MMA fights.

Variable	Mean value for those conscious	Mean value for those unconscious	P-value	Odds Ratio	Missing Values
Round Number	1.91	1.46	.000	.000	0
Offensive Passes	0.22	0.19	.001	.047	0
Body Jabs Landed	0.33	0.21	.000	.000	0
Body Power Landed	0.67	0.45	.000	.000	0
Clinch Head Jabs Landed	0.82	0.63	.000	.000	0
Clinch Body Power Landed	0.68	0.57	.000	.000	0
Ground Head Jabs Landed	1.16	0.67	.000	.000	0
Ground Head Power Landed	0.70	0.52	.000	.000	0
Head Jabs Landed	0.78	0.63	.010	.000	0
Head Power Landed	1.34	1.13	.000	.000	0
Stand Ups	0.47	0.28	.000	.000	0
Takedowns Landed	0.30	0.24	.000	.000	0
Total Strikes Landed	3.20	2.43	.001	.000	0
Significant Strikes Landed	2.13	1.79	.105	.000	0
Significant Head Strikes Landed	1.41	1.16	.000	.000	0

Significant Distance Strikes Landed	1.32	1.16	.000	.000	0
Significant Body Strikes Landed	0.78	0.62	.000	.000	0
Advance to Half-Guard	0.10	0.08	.000	.010	0
Significant Ground Strikes Landed	0.32	0.22	.000	.000	0
Significant Clinch Strikes Landed	0.65	0.56	.016	.000	0
Significant Distance Head Strikes Landed	1.04	0.87	.135	.000	0
Significant Ground Head Strikes Landed	0.28	0.19	.000	.000	0
Significant Distance Body Strikes Landed	0.51	0.38	.000	.000	0
Significant Clinch Head Strikes Landed	0.36	0.32	.000	.009	0
Ground Body Jabs Landed	0.43	0.29	.000	.000	0
Clinch Body Jabs Landed	0.51	0.39	.000	.000	0
Clinch Head Power Landed	0.50	0.44	.000	.002	0
Total Ground Head Strikes Landed	0.83	0.51	.000	.000	0
Total Clinch Body Strikes Landed	0.55	0.45	.000	.000	0
Total Clinch Head Strikes Landed	0.80	0.66	.000	.000	0
Total Distance Head Strikes Landed	1.04	0.87	.135	.000	0
Total Ground Body Strikes Landed	0.34	0.21	.000	.000	0

Table 5.6 Independent sample t-tests for variables in the data-set used to determine the factors associated with being diagnosed with a concussion among the fighters rendered unconscious.

Variable	Mean value for those not concussed	Mean value for those concussed	P-value	Odds Ratio	Missing Values
Age	25.51	31.55	.244	.000	0
Number of Professional Fights	10.40	20.61	.000	.000	0
Time between Previous Fight in Months	6.40	5.90	.572	.430	0
Round Number	1.53	1.46	.744	.550	0

B. Discrete Variables

Chi-square analyses were tabulated for discrete covariates in the data-set against the dichotomous outcome along with the p-values.

Table 5.7 Chi-square results for variables in the data-set used to determine the factors associated with being rendered unconscious in professional MMA fights.

Variable	Response	% Unconscious	P-value of x^2 test	Missing Values
Distance Knockdowns	Yes No	28.7 22.9	0.053	0
Advance to Mount	Yes No	28.5 22.9	0.062	0
Advance to Back	Yes No	18.4 23.2	0.043	0
Significant Clinch Body Strikes Landed	Yes No	19.4 25.0	0.000	0
Significant Distance Body Strikes Landed	Yes No	18.4 26.8	0.000	0
Takedown Slams	Yes No	23.6 23.0	0.447	0
Takedown Shots Landed	Yes No	15.6 23.7	0.000	0

Table 5.8 Chi-square results for variables in the data-set used to determine the factors associated with being diagnosed with a concussion among the fighters rendered unconscious.

Variable	Response	% Diagnosed Concussion	P-value of x^2 test	Missing Values
Ethnicity	White Other	68.6 62.6	.215	0
Weight Class	Heavyweight Middle/Welter Weight Other	70.1 65.5 61.2	.330	0

Gender	Male Female	65.9 70.6	.459	0
Ending Strike Description	Yes No	Cell sizes too small	-	-
Ending Position	At Distance Other	66.9 64.6	.429	0
Ground Body Jabs Landed	Yes No	61.9 66.7	.414	0
Clinch Body Jabs Landed	Yes No	78.9 63.7	.049	0
Clinch Head Power Landed	Yes No	74.1 63.6	.094	0
Head Power Landed	Yes No	73.9 59.2	.013	0
Head Jabs Landed	Yes No	77.9 59.3	.003	0
Total Ground Head Strikes Landed	Yes No	64.4 66.7	.453	0
Total Clinch Body Strikes Landed	Yes No	75.6 61.4	.021	0
Total Clinch Head Strikes Landed	Yes No	70.4 64.3	.229	0
Total Distance Body Strikes Landed	Yes No	67.1 65.8	.486	0
Total Distance Head Strikes Landed	Yes No	73.3 56.3	.005	0
Significant Clinch Body Strikes Landed	Yes No	74.2 63.0	.069	0
Significant Clinch Head Strikes Landed	Yes No	74.1 63.6	.094	0
Significant Distance Body Strikes Landed	Yes No	67.1 65.8	.486	0
Significant Distance Head Strikes Landed	Yes No	73.3 56.2	.005	0
Significant Ground Head Strikes Landed	Yes No	75.0 65.6	.318	0
Significant Ground Strikes Landed	Yes No	72.2 65.7	.391	0
Significant Clinch Strikes Landed	Yes No	71.4 62.8	.114	0
Significant Distance Strikes Landed	Yes No	70.4 51.9	.011	0
Significant Body Strikes Landed	Yes No	70.0 62.7	.176	0
Significant Head Strikes Landed	Yes No	72.0 54.0	.025	0
Significant Strikes Landed	Yes No	69.8 43.8	.013	0
Total Strikes Landed	Yes No	69.4 42.8	.012	0
Takedowns Landed	Yes No	54.5 67.5	.163	0
Stand-Ups	Yes No	68.6 65.8	.457	0

Ground Head Power Landed	Yes No	75.0 65.6	.318	0
Ground Head Jabs Landed	Yes No	62.5 67.0	.353	0
Clinch Body Power Landed	Yes No	74.2 63.0	.069	0
Clinch Head Jabs Landed	Yes No	72.1 64.9	.237	0
Body Power Landed	Yes No	70.2 64.9	.289	0
Offensive Passes	Yes No	66.7 66.2	.621	0
Catchweight	Yes No	60.0 66.4	.549	0
Previous Concussion	Yes No	80.7 50.9	.000	0

3. Detection of Interactions

Preliminary logistic regression was performed, featuring punitive interaction terms along with initial explanatory variables. Interaction terms tested were those deemed potentially collinear via bivariable analyses, and those identified in the logistic regression analysis of earlier analyses. Interactors are defined as those with associations resulting with a p-value <0.05. This formula for detection of interaction was only used for the subset of data to determine the factors associated with being diagnosed with a concussion among the fighters rendered unconscious.

Table 6. Significance of putative interactions for logistic regression on data-subset.

Putative Effect Modifier	**β**	**Standard Error of β**	**Wald X^2**	**P-value**	**Modifier?**
"Age" X "Number of Professional Fights"	-.022	.027	.675	.411	No
"Age" X "Previous Concussion"	.348	.308	1.274	.259	No
"Gender" X "Weight Class"	.182	.205	.790	.374	No

4. Operational Confounders

Using the definition of Kleinbaum et al, variables whose removal from the model resulted in a 10% or greater change in β for the primary explanatory variable (diagnosed concussion) are confounders. The identification of confounders was only used for the subset of data to determine the factors associated with being diagnosed with a concussion among the fighters rendered unconscious.

Table 7. Identification of confounders for data-subset to determine the factors associated with being diagnosed with a concussion.

Putative confounder	**β of diagnosed concussion in full model**	**β of diagnosed concussion w/o variable**	**% difference**	**Confounder?**
Round Number	-35.138	-29.543	16	Y*
Gender	-35.138	-28.867	18	Y*
Age	-35.138	-2.531	93	Y*
Number of Pro Fights	-35.138	-22.433	36	Y*
Previous Concussion	-35.138	-31.871	9	N
Time between fights in months	-35.138	-31.121	11	Y*
Ethnicity	-35.138	-30.824	12	Y*
Weight Class	-35.138	-34.744	1	N
Age x Pro Fights	-35.138	-26.962	23	Y*
Age x Previous Concussion	-35.138	-32.237	8	N
Total Strikes Landed	-35.138	-34.505	2	N
Significant Strikes Landed	-35.138	-32.059	9	N
Significant Head Strikes Landed	-35.138	-35.160	<1	N
Significant Body Strikes Landed	-35.138	-34.762	1	N
Significant Distance Strikes Landed	-35.138	-34.699	1	N
Significant Clinch Strikes Landed	-35.138	-31.023	12	Y*
Significant Ground Strikes Landed	-35.138	-34.779	1	N

Significant Distance Head Strikes Landed	-35.138	-34.630	2	N
Significant Distance Body Strikes Landed	-35.138	-34.630	1	N
Significant Clinch Head Strikes Landed	-35.138	-34.630	1	N
Significant Clinch Body Strikes Landed	-35.138	-34.630	1	N
Total Clinch Head Strikes Landed	-35.138	-34.401	2	N
Total Clinch Body Strikes Landed	-35.138	-35.535	<1	N
Total Ground Head Strikes Landed	-35.138	-31.308	11	Y*
Head Jabs Landed	-35.138	-34.520	2	N
Head Power Landed	-35.138	-34.186	3	N
Body Power Landed	-35.138	-33.864	4	N
Takedowns Landed	-35.138	-34.590	2	N
Clinch Head Jabs Landed	-35.138	-34.690	1	N
Clinch Body Jabs Landed	-35.138	-34.144	3	N
Ground Head Jabs Landed	-35.138	-29.781	15	Y*
Ground Body Jabs Landed	-35.138	-33.965	3	N
Round Standups	-35.138	-33.835	4	N

5. Goodness of Fit

For all research questions, the Goodness-of-fit statistic of Hosmer and Lemeshow was used to assess the fit each stage of the logistic regression procedure.

Table 8. Hosmer-Lemeshow goodness-of-fit Test Statistics for first logistic regression analysis.

Model	**Chi-square**	**Degrees of freedom**	**Significance**
All covariates	12.895	8	.116

Table 9. Hosmer-Lemeshow goodness-of-fit Test Statistics for second logistic regression analysis.

Model	**Chi-square**	**Degree of freedom**	**Significance**
Initial covariates without interaction term	11.590	8	.170
Including interaction terms	5.153	8	.741
With confounders and interaction terms forced in	4.030	8	.854

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