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Original Research

Injury rate and pattern among Brazilian jiu-jitsu practitioners: A survey study

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ABSTRACT

Objective: To determine the 6-month incidence rate and pattern of Brazilian jiu-jitsu (BJJ)-related injuries and characterize associations between injuries and experience level, demographic factors, and training variables.
Design: Descriptive epidemiology study.
Setting: Online survey.
Participants: 1287 adult BJJ practitioners.
Outcome measures: 6-month BJJ-related injury incidence, anatomical pattern of injuries, and injury-associated demographic and training variable identification.
Results: 59.2% of practitioners reported at least one injury over 6 months. The knee was the most common site. Logistic regression analysis demonstrated 6-month injury incidence was negatively associated with years of training and body weight, and positively associated with training days per week and instructor status. More experienced athletes were more likely to report low back injury, while less experienced athletes more frequently reported head, upper extremity, and elbow injuries. None of the following variables were predictive of injury risk: gi preference, instruction on break-falling, and participation in a structured beginner's program.
Conclusions: The risk factor analysis is applicable to BJJ instructors interested in reducing student injury risk. The widespread pattern of injuries and the distinction between types of injuries sustained at different levels of experience are notable findings that sports medicine practitioners should keep in mind when working with BJJ athletes.

1. Introduction

Brazilian jiu-jitsu is a rapidly growing martial art/sport that achieved worldwide exposure with The Ultimate Fighting Championship in 1993 (Snowden, 2018). Since this time BJJ has come to be recognized as a fundamental discipline for mixed martial artists (James, Haff, Kelly, & Beckman, 2016; Jensen, Maciel, Petrigliano, Rodriguez, & Brooks, 2017). In terms of its growth as a sport beyond its application in Mixed Martial Arts; the International Brazilian Jiu Jitsu Federation (IBJJF) expanded from holding 3 tournaments within Brazil in 1996 to 128 tournaments worldwide in 2017 (Results - IBJJF, 2018).

Similar to other martial arts, increasing skill in BJJ is rewarded via belt rank advancement. Distinct however, is BJJ's focus on grappling, as opposed to striking, as the means by which a practitioner uses the art to defend himself or compete in sanctioned athletic events. Consequently, results from previous epidemiological studies of martial arts injuries may have little resemblance to the injury pattern sustained by BJJ practitioners. Birrer and Halbrook specifically excluded grappling arts such as judo and jiu-jitsu from their 5-year retrospective analysis of martial arts injuries published in 1988 (Birrer & Halbrook, 1988). Further, while a 25-year retrospective analysis also published by Birrer in 1996 did include judo in its martial arts injury epidemiology analysis, these athletes made up only 7% of the study population (Birrer, 1996).

While there is considerable variability in teaching methods and class structure across BJJ academies, including: whether a beginner's class is required, whether break-falling (ukemi) is taught, and how much sparring is performed; a typical BJJ class starts with a warm-up, which is followed by technique instruction, and then live sparring. In competition, athletes are matched by age, sex, and belt

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color/skill level; and may compete wearing either a gi (two-piece cotton garment consisting of loose pants and a wrap-around jacket closed with a belt) or shorts and a rash guard (a tight-fitting shirt typically made from spandex and nylon), referred to as "no-gi". Most rule sets allow for takedowns and grappling on the ground without striking, with the objective of forcing one's opponent to submit via joint lock application or choke. In lieu of obtaining a submission, an athlete may win by outscoring his opponent via attaining dominant position, takedowns and reversals from bottom, and near-submissions.

Given the rise in BJJ popularity and its technical differences with other martial arts forms, interest in BJJ research has increased, both in terms of identifying its unique physiologic demands and the injury patterns affecting its practitioners. A 2017 systematic review of the physical and physiologic characteristics of competitive BJJ athletes from 58 studies including 1496 subjects found that while aerobic fitness does not seem to distinguish between competitive levels as it does in other martial arts forms; upper extremity power, muscular endurance, and flexibility increase with higher competitive levels (Andreato, Lara, Andrade, & Branco, 2017).

Previously previously published articles investigating BJJ injury epidemiology have varied widely in terms of study populations, time period over which injuries were counted, injury definitions, outcome measures, and results (das Graças et al., 2017; Usuki, Rosen, Jawed-Wessel, Grandgenett, & McGrath, 2017; Machado, Machado, & De Marchi, 2012; McDonald, Murdock, McDonald, & Wolf, 2017; Kreiswirth, Myer, & Rauh, 2014; Scoggin et al., 2014; Da Silva Junior, Kons, Dellagrana, & Detanico, 2018). In terms of injury definitions, these varied from fairly flexible with Das Gracas' definition of "any self-reported manifestation of pain or physical dysfunction secondary to jiu jitsu resulting in training alterations" to more stringent with McDonald's requirement for physician visit or abstaining from BJJ training for at least one week (das Graças et al., 2017; McDonald et al., 2017). Most studies were limited to a few hundred athletes[8,9,10,1114]. The largest studies reported exclusively on injuries sustained during competition (Kreiswirth et al., 2014; Scoggin et al., 2014).

As a result, a study providing a larger scale, more general adult BJJ injury epidemiology analysis across experience levels utilizing an established definition for injury is needed. The objectives of this study were to determine the self-reported 6-month injury incidence and pattern sustained by adult BJJ participants, and to identify demographic factors and training variables related to these injuries. We were interested in a broad range of self-reported musculoskeletal, neurological, or visceral injuries that were significant enough to limit training or required a visit to a health care professional. A 6-month incidence was selected, as we believed that this time period was long enough to yield a sufficiently large sample of injuries, but short enough not to confound the effects of increased experience on injury incidence (6 months is less than the minimum amount of time a practitioner is required to spend at each belt level prior to rank promotion (IBJJF Graduation System, 2015)). We further sought to evaluate the effects of gi vs. no-gi preference, ukemi instruction, and beginner's programs on injury risk.

2. Materials and methods

Prior to recruiting respondents for the study, the study protocol and survey were approved by the University of Miami Institutional Review Board. A waiver of written consent was obtained.

2.1. Survey

The survey was modeled after Weisenthal et al.'s CrossFit study, and modified with input from the lead author (C.M.) and several other experienced BJJ practitioners (Weisenthal, Beck, Maloney, DeHaven, & Giordano, 2014). It consisted of 82 questions accessible via a link shared on the lead author's Facebook page from October 10th to October 17th, 2017. Participants encountered the link by visiting the lead author's Facebook page, by seeing the link shared on another BJJ practitioner's Facebook page, or were recruited by listening to The Grappling Central Podcast to the podcast webpage, where the survey was also shared (Podcast, 2017). The survey was constructed and managed using REDCap software (Harris, Taylor, Thielke, Payne, & Nathaniel Gonzalez, 2009).

Upon clicking on the Facebook link, potential subjects first encountered an introductory statement that discussed the study purpose and implication of informed consent should the subjects complete all survey questions. The first question set in the survey elicited demographic information, including age (open text for inputting years of age); height (open text for inputting height in inches); weight (open text for inputting weight in pounds); and sex (options: male or female). The next question set collected information about the following BJJ training variables: years of BJJ training (open text, with decimals allowed); number of BJJ training days per week (1-2, 3, 4, 5, 6, or 7 days); average training session duration (less than 1 h, 1–1.5 h, 1.5–2 h, more than 2 h); percentage of time spent training with and without the gi (less than 25%, 25% - 49%, 50% - 74%, 75% - 99%; 100%); percentage of BJJ classes involving sparring (less than 25%, 25% - 49%, 50% - 74%, 75% - 99%, 100%); typical activities preceding sparring (aerobic warm-up, stretching, stretching plus aerobic warm-up, technique instruction, none); average duration of sparring (open text for inputting minutes); presence vs. absence of ukemi instruction at one's academy (yes - ukemi is taught, no – ukemi is not taught); status as an instructor (instructor or not an instructor); and presence or. absence of a beginner's program at one's academy.

Survey respondents were then asked whether (yes or no), and how many (0, 1, 2, 3, 4, 5 or more) injuries they sustained during the past 6 months, based on whether the injury met at least one of the following three criteria: (1) complete abstention from BJJ training and any outside physical activity for > 1 week, (2) modification of BJJ training and outside physical activity for > 2 weeks, or (3) evaluation by a medical professional (Weisenthal et al., 2014). If the respondent reported having had an injury during the past six months, a series of follow-up questions was asked about the details of up to three of these injuries. These questions included: which of the three criteria of injury were met; what type of medical professional was seen (if any); the general body area that was injured (e.g., head, chest, back, legs); the specific body part that was injured (e.g., nose, eye, lower back, ankle); whether the injury occurred during training or during competition; and what the suspected injury cause was (accident during warm up, fall from a throw or takedown, opponent did not give you time to tap out to a submission, you waited too long to tap out, accident during a scramble/transition, other).

1568 surveys were submitted. After removal of duplicate and incomplete entries, data from 1321 respondents who completed demographic and BJJ training history information were included. For purposes of injury analyses, data from the 1287 participants who fully completed this section were used.

2.2. Statistical analyses

IBM SPSS version 24 was used to perform data analyses. Logistic regression analysis was performed to identify significant predictors of injury occurrence (presence or absence of any injury) during the previous 6-months. Odds ratios (OR), 95% confidence intervals (95%

CI), and p-values were calculated for each predictor variable of interest. Pearson's chi-square tests and student t-tests were conducted to evaluate risk factors for the presence of injury in specific body locations. In addition, to compare the likelihood of injury for different groups of BJJ practitioners, we created an ordinal variable to represent injury frequency by exposure calculated by dividing the number of injuries reported during the past 6 months by the product of the number of days per week attending BJJ training, the number of sessions per day of training, and the amount of time during each training session. Because this "injury incidence/ training frequency" variable was based on self-reported estimates of average time training collected using ordinal categories (i.e., not continuous metrics), we performed non-parametric tests to assess trends in injury frequency across different participant parameters: a) Mann-Whitney *U* test to compare men to women; b) Spearman's rank-order correlation to assess the relationship between injury incidence/ training frequency and age and weight.

3. Results

The average age of the survey respondents was 29.5 (±2.12 (1 standard deviation)) with an average of 7.5 (±3.54) years of BJJ experience. Further details of the distribution of survey respondent characteristics can be found in Table 1.

Of the 1287 respondents who answered the question regarding the number of injuries the athlete had during the past 6 months, 41.0% (n = 528) reported having no injuries, and 59.0% (n = 759) experienced at least 1 injury.

Fig. 1 presents the frequency BJJ-related injury frequency (1035 total injuries reported in detail) with regard to body area and body part. The majority of injuries occurred during a scramble or transition (58.5%), with fewer due to a fall from a throw or takedown (5.9%), waiting too long to tap out to a submission (8.9%), not being given time to tap out to a submission (6.3%), an accident during warm-up (3.5%), or other (16.9%). Those respondents reporting "other" as an injury cause were given an opportunity to briefly describe the possible cause. While responses were disparate, the most common attributions were to: chronic injury recurrence, poor warm-up, overtraining, old age, and an unsafe training partner.

Table 1
Demographic and BJJ history of survey respondents.

Characteristic	Percentage (n)
Age group (years)	
18 - 25	14.1 (186)
26 - 35	42.1 (556)
36 - 45	32.8 (433)
46 - 55	9.5 (126)
> 55	1.6 (21)
Sex	
Male	84.5 (1120)
Female	15.5 (206)
Weight (lbs)	
≤ 150	17.0 (224)
151 - 175	32.8 (433)
176 - 200	28.0 (366)
201 - 225	12.7 (168)
≥ 226	9.7 (128)
Length of time practicing BJJ (years)	
≤ 1	8.6 (113)
1 - 4	36.4 (481)
> 4 - 7	29.1 (383)
> 7–10	13.5 (178)
> 10	12.6 (166)
Do you compete in sport BJJ?	
Yes	66.5 (881)
No	33.5 (444)

3.1. Factors affecting 6-month injury incidence

Table 2 lists the odds ratios (ORs), 95% confidence intervals (CIs), and associated p-values for all variables included in the logistic regression model where the presence of any qualifying injury during the past six months was the dependent variable. Significant predictors of having a BJJ-associated injury included lower weight, being an instructor, fewer years practicing BJJ, and participating in more BJJ classes per week. Age and minutes spent sparring per BJJ class had a tendency to impact the presence of an injury during the past 6 months, but sex, use of a gi, practice of ukemi, and competitive status did not impact the 6-month injury incidence.

To further investigate the impact of demographic characteristics on the risk for injury, the calculated variable "incidence of injury/ frequency of training" was used. Using this analysis, sex did not significantly impact the risk for injury (Mann-Whitney *U* test, $p = 0.96$), neither did age nor weight (Spearman's row $= -0.049$ ($p = 0.085$) and -0.034 ($p = 0.238$)).

To evaluate the effect of experience level on injury incidence at specific anatomical locations, t-tests were used to compare the average years of BJJ experience between those who had an injury to a specific location and those who did not have an injury in that location. Head (5.3 vs. 5.8 years, $p = 0.007$), upper extremity (4.8 vs. 5.8 years; $p < 0.001$), and elbow (4.3 vs. 5.7 years; $p = 0.007$) injuries were associated with fewer years of BJJ experience. Spine (6.5 vs. 5.5 years; p 0.024), and lower back (7.8 vs. 5.4 years; $p < 0.001$) injuries were more common in experienced practitioners. Due to a modest correlation between the number of years of BJJ practice and respondent age (Pearson $r = 0.324$; $p < 0.001$), we tested for the confounding effect of age on the differences attributed to years of BJJ practice for these locations. For the head, upper extremities, and lower back, age did not significantly impact the effect of years of BJJ practice on injury incidence. However, for the spine, including age as a predictive factor in a logistic regression of injury incidence altered the effect of increased experience to a nonsignificant contribution.

3.2. Use of gi

We investigated the effect of gi preference on injury incidence by comparing those who reported wearing a gi 100% of the time to those who reported wearing a gi less than 50% of the time. No difference in the overall 6-month injury incidence was found between these two groups. However, the 100% group reported significantly fewer ankle injuries (3.6%) than did the less than 50% group (9.2%; Pearson Chi-square, $p = 0.030$).

3.3. Beginner's classes

Of those respondents who reported between six months and two years of BJJ experience, there was no difference in injury incidence between those who took a beginners class (63.5%; 66 of 104) and those who did not (63.4%; 175 of 276) (Pearson Chi-square; $p > 0.05$).

3.4. Ukemi instruction

Of those respondents who reported an injury resulting from a throw or takedown, there was no difference in injury incidence between those who reported no ukemi instruction at his academy (6.2%) and those who did learn ukemi at the academy (6.5%) (Pearson Chi-square; >0.05).

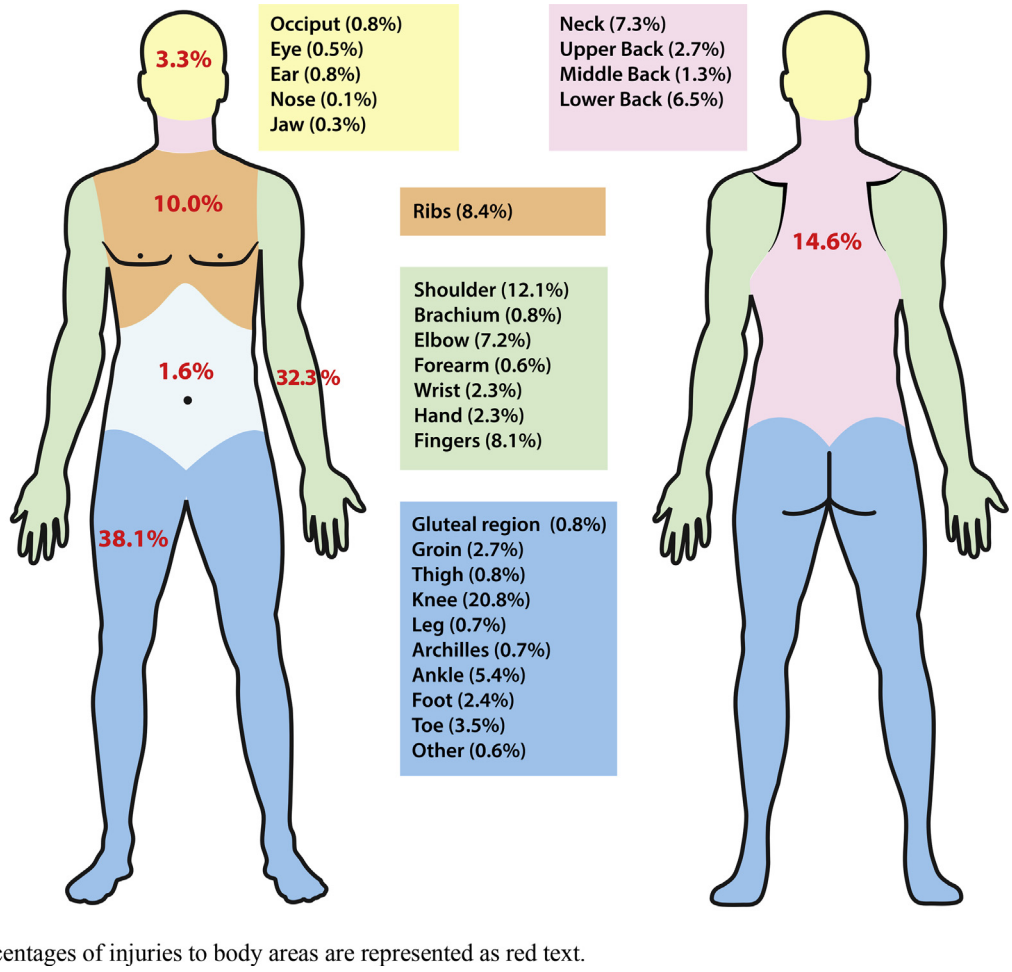

Fig. 1. Injury location.
*Percentages of injuries to body areas are represented as red text.

Table 2
Factors contributing to 6-month incidence of BJJ-related injury.

Predictor	Odds Ratio	95% CI	p-value
Categorical variables			
Sex [female vs. male]	1.301	0.897, 1.885	0.165
Instructor? [no vs. yes]	2.004	1.379, 2.914	<0.001
Competitor status [train only vs. compete]	0.959	0.733, 1.253	0.758
Use of gi [≤50% of time vs. >50% of time]	1.337	0.926, 1.931	0.122
Ukemi [no vs. yes]	0.915	0.691, 1.211	0.535
Ordinal and continuous variables			
Age (years)	1.014	0.998, 1.030	0.085
Weight (lbs)	0.994	0.992, 0.998	0.002
Duration of BJJ practice (years)	0.928	0.898, 0.958	<0.001
Frequency of BJJ class (days per week)	1.157	1.034, 1.294	0.011
Time spent sparring per class (minutes)	1.009	1.000, 1.018	0.052

4. Discussion

With 759 subjects reporting at least one injury over 6 months, this study is the largest survey of BJJ injuries currently available in the peer-reviewed literature. Further, the 84.5% male response is consistent with the two previous BJJ injury epidemiology studies that reported responses from both male and female subjects (das Graças et al., 2017; McDonald et al., 2017). A 59% 6-month BJJ-related injury incidence was found, with the knee as the most commonly injured location (20.8%) and the majority of injuries resulting from an accident during a scramble or transition (58.5%). Factors associated with increased risk for injuries over this time period included: lower weight, instructor status, fewer years of BJJ training, and more training days per week. Injuries to the head, upper extremity, and elbow were more common in less experienced practitioners, while low back injuries more commonly affected seasoned practitioners. The inclusion of beginner's classes did not influence injury incidence in practitioners with less than 2 years of experience. Neither break-falling nor reduced gi use affected overall 6-month injury risk. However, decreased gi usage

predicted increased risk for ankle injury.

As there are no studies presenting a 6-month injury incidence to which direct comparisons are possible, the 59.2% from the current study can only be compared to 12-month injury incidences reported by two previous studies (Machado et al., 2012; McDonald et al., 2017). Machado, Machado, and De Marchi reported a 12-month injury incidence of 75% from a sample of 256 male athletes competing at the 2006 World Brazilian Jiu Jitsu Championships (Machado et al., 2012). While their study definition for injury allowed for lesions not requiring loss of training time, 67% of the injuries reported met the requirements for injury in the current study. With this consideration, the corrected 12-month injury incidence would have been 52.9%. McDonald's 2017 study of 140 male and female BJJ practitioners found an incidence of 85.7% (McDonald et al., 2017). Although his injury definition stipulated a one-week abstention from training, the inclusion of skin infections as a qualifying category inflated total injury incidence.

In the present study the most commonly injured body part was the knee (20.8% of total injuries reported). This is consistent with the results from both Machado et al. and Usuki et al., who found knee injury incidences of 28% and 26.5%, respectively (Machado et al., 2012; Usuki et al., 2017). Additionally, Kreiswirth et al. reported the knee and elbow as the most commonly injured body parts, at 19.4% each, in a study of 951 male competitors at the Jiu Jitsu No-Gi World Championship (Kreiswirth et al., 2014). The current study results differ however from those of Scoggin et al., McDonald et al., and Das Gracas et al.; who reported the elbow, the shoulder, and the hand/fingers as the most commonly injured locations, respectively (das Graças et al., 2017; McDonald et al., 2017; Scoggin et al., 2014). Of note, both Scoggin et al.'s and Das Gracas et al.'s studies included participants under 18 years old, with 10.8% of Scoggin et al.'s participants under the age of 16. The most common injury mechanism in Scoggin et al.'s on-site analysis of 46 competition-related injuries was an armbar (Scoggin et al., 2014). While Scoggin et al. specified the incidence rates for participants <16 years and participants >16 years, he did not specify differences in injury locations between the two groups. Das Gracas et al.'s study of 193 athletes training in jiu jitsu for at least 12 months only presented injury incidences of the upper extremities (das Graças et al., 2017). So it is unclear whether the knee could have been the most commonly injured body part overall.

The most common context for injury in the current study was a scramble/transition during sparring or competition. The term(s) scramble/transition was used to refer to anything other than a takedown, or applying or defending a submission that could occur during live training or a match. This finding is consistent with results from Das Gracas et al.'s study in regard to adolescent (12–17 years old) and adult (18–30 years old) sub-groups, as well as to the master (>30 years old) sub-group when the categories of "tumbling/trauma" and "sweep" are combined (das Graças et al., 2017). This finding is likely secondary to the fact that the majority of time during sparring and competition is spent trying to establish dominant position from which one athlete's opponent can be submitted. On the contrary, both the Scoggin et al. and Usuki et al. studies found that the highest percentage of injuries occurred secondary to submission attempts (Scoggin et al., 2014; Usuki et al., 2017).

The only demographic variable found to predict BJJ-related injury in the current study was lower body weight. Similarly, McDonald et al. found an injury incidence nearly 73% greater for athletes within the lower 5 wt classes compared to those within the higher 5 wt classes (McDonald et al., 2017). Both Scoggin et al. and Das Gracas et al. reported an association between older age and increased injury risk (das Graças et al., 2017; Scoggin et al., 2014). As was the case with increased upper extremity injury incidence however, it is possible that the inclusion of younger participants may have also played a role in this finding. Further, Scoggin et al.'s comparisons of injury incidence between the two age groups was likely limited by only having 5 participants in the under 16 group.

Instructor status, fewer years of experience, and more training days per week were found to be associated with increased injury risk in our study. While instructors likely have greater exposure to potential injury than the average student, it was thought that this potential risk could be offset by increased experience in dealing with prior injuries as well as having the responsibility for maintaining safety on the training mat. However, despite the finding that more years training was protective against injuries over 6-months, this did not compensate for an instructor's increased injury exposure.

Years of BJJ training was used instead of belt rank to evaluate the effect of training experience on 6-month injury incidence. This was done to prevent exclusion of athletes training no-gi exclusively and not following a belt system for rank progression. Greater training experience was found to be a significant protective factor against a new injury over the prior 6 months. This result stands in contrast to the Kreiswirth et al. study, which found increased injury incidence rates for brown and black belts compared to blue and purple belts (Kreiswirth et al., 2014), and a recent publication by Da Silva et al., who reported increased prevalence of BJJ competition-related injuries for advanced athletes (purple belt and above) relative to novice athletes (white and blue belts) (Da Silva Junior et al., 2018). The discrepancy with the results from Kreiswirth's study could be the result of greater variance with respect to experience level in the current study, as the least experienced subjects in Kreiswirth's sample were blue belts. Additionally, matches are longer for higher belt levels in IBJJF tournaments, which result in greater exposure to injury. With regard to the discrepancy with the findings from Da Silva et al., direct comparison is difficult, as it unclear how it was determined if injures reported by the surveyed athletes in the study actually occurred within the experience level (novice or advanced) to which they were assigned.

Despite the protective effect of experience on injuries overall, injuries to specific body areas/parts were noted to segregate with respect to years of training as follows: experienced practitioners were found to be at greater risk for lumbar spine injury, while less experienced practitioners were found to more frequently injure the head, upper extremity, and elbow. The positive association between years of experience and new-onset lumbar spine injury is logical when one considers that a major contributor to this type of injury is cumulative exposure to cyclic bouts of flexion/extension (Callaghan, Gunning, & McGill, 1998). However, the Reis et al. study did not find an association between years of training and presence of chronic low back pain (Reis, Dias, Newlands, Meziat-Filho, & Macedo, 2015). They reported, instead, that chronic low back pain prevalence was dependent exclusively on longer training session duration, which appeared to be largely explained by a participant's status as a professional athlete (Reis et al., 2015). It is important to note however that acute low back pain as reported in our study is understood to be a distinct diagnostic entity from chronic low back pain in the pain literature (Sanzarello et al., 2016).

While a greater number of BJJ classes per week was found to be predictive of injury, total time spent sparring only trended towards significance. This was an interesting finding given that both variables reflect increased exposure to sparring. Two potential contributors to this discrepancy may be the motivation of participants who train more days per week and the potential variability in intensity associated with different sparring durations. Interestingly there was no significant association between injury risk and those identifying as competitors.

The current study is the first to compare injury incidence for gi

versus no-gi grappling. In addition to decreased friction and elimination of several gi-dependent choking techniques when training no-gi, rules often differ between gi and no-gi competition, especially with regard to legality of leg locking techniques. While most leg locks are illegal until the brown belt level in IBJJF competition, they are fairly ubiquitous across no-gi grappling tournaments (Rule Book General Compet, 2015). Additionally, the heel hook (a submission applied by isolating an opponent's lower extremity and generating a rotational torque across the ankle) is widely popular in no-gi competition, but not permitted at any belt level by the IBJJF (Rule Book General Compet, 2015). As there were very few respondents who reported training >75% without the gi, we compared participants who reported training with the gi 100% of the time to those training <50% of the time with the gi. While there was no significant difference between these groups in terms of total injury incidence, when evaluating injuries to specific body parts, athletes training with the gi < 50% of the time were found to be 2.55 times more likely to sustain an ankle injury.

The inclusion of a beginner's program in an academy's curriculum did not reduce injury risk. This may suggest that instructors may be overestimating the effect of technique acquisition and underestimating the novelty of grappling and exposure on injury risk for new students. Additionally, sparing participation between inexperienced practitioners in such a class could potentially increase injury frequency. Unfortunately, the current study did not examine heterogeneity of program design and sparring participation in beginner's programs across academies.

Break-falling also failed to demonstrate injury reduction benefit in the current study. Such instruction is indispensable in judo, in which the most common injury mechanism is being thrown (Pocecco et al., 2013). The reduced emphasis on throwing techniques in BJJ in favor of groundwork and the ability to “pull guard” in competition may explain this discrepancy.

A limitation of the current study is the survey design. The results were dependent upon accurate subject reporting of several details for up to 3 injuries over 6 months. In a study of 12-month injury recall accuracy by Australian football players, Gabbe et al. found that while 80% of subjects were able to accurately state the number and location of their injuries, only 61% were able to correctly recall the actual diagnosis (Gabbe, Finch, Bennell, & Wajswelner, 2003). As a result of this and the fact that medical professionals did not see many of the respondents, we chose not to analyze the specific diagnosis that the respondents provided. An additional limitation is the absence of an hourly incidence rate. While it would have been possible to estimate such a rate based upon reported training frequency, this estimation would have necessarily had to ignore the effects of time lost secondary to injury as well as the number of matches participated in by those respondents identifying as competitors. As a result, a 6-month injury incidence was thought to be a more practical measure by which to report BJJ-related injuries resulting from diverse exposures.

5. Conclusion

The current study represents the largest and most comprehensive risk factor analysis of BJJ-related injuries to date. It is the first study to report on the effects of commonly instituted practices within the BJJ community such as including beginner's programs and break-falling instruction, It is also the only study currently available in the literature to report on the effects of gi preference on injury risk. Therefore, this study has the potential to impact current teaching methodologies, training regimens, and safety practices at BJJ academies around the world.

One area to which this study directly applies is curriculum design for beginner's programs. In the principal investigator's experience, introductory lessons in BJJ largely focus on teaching new students basic techniques. As a consequence, little time is spent on making them aware of potentially dangerous mistakes that beginners often make during live sparring. An example situation might be a student standing up in an attempt to pull his arm out of an armbar. This is a natural reflex, but has dangerous consequences as it accelerates the opponent's extension of the student's elbow, which in turn gives him less time to submit prior to sustaining elbow injury.

A study finding that deserves further investigation is increased low back injury risk in more experienced BJJ athletes. While stylistic adjustments to reduce injury risk are commonly made over an athlete's career across sports, such adjustments to reduce low back injury risk in BJJ athletes may be relatively limited. This is because two positions in which a BJJ athlete will most often find himself: passing the open guard and defending the open guard, necessarily expose the lumbar spine to repetitive flexion and extension cycles under a compressive load. However, periodically incorporating a position such as half-guard (in which a training partner's bodyweight does not have to be accepted in lumbar flexion) in place of open guard may potentially mitigate some of the risk. Further, temporal adjustments to training may also possibly decrease lumbar injury incidence. Snook et al. reported significant reductions in low back pain intensity with avoidance of lumbar flexion for the first 2 h following rising from bed (Snook, Webster, McGorry, Fogelman, & McCann, 1998). This reduction was thought to be a consequence of decreased loading of a fully hydrated intervertebral disc. These findings suggest that experienced BJJ practitioners may be better off delaying training until the afternoon or evening.

Declarations of interest

None.

Ethical statement

Institutional Review Board approval was obtained through the University of Miami Human Subjects Research Office.

Conflicts of interest

None Declared.

Ethical approval

Institutional Review Board approval was obtained through the University of Miami Human Subjects Research Office.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.06.012.

References

Andreato, L. V., Lara, F. J. D., Andrade, A., & Branco, B. H. M. (2017). Physical and physiological profiles of Brazilian jiu-jitsu athletes: A systematic review. *Sport Med - Open, 3*(1). https://doi.org/10.1186/s40798-016-0069-5.

Birrer, R. B. (1996). Trauma epidemiology in the martial arts: The results of an eighteen-year international survey. *The American Journal of Sports Medicine, 24*(6_suppl), S72–S79. https://doi.org/10.1177/036354659602406s21.

Birrer, R. B., & Halbrook, S. P. (1988). Martial arts injuries the results of a five year national survey. *The American Journal of Sports Medicine, 16*(4), 408–410.

Callaghan, J. P., Gunning, J. L., & McGill, S. M. (1998). The relationship between lumbar spine load and muscle activity during extensor exercises. *Physical Therapy*. https://doi.org/10.1093/ptj/78.1.8.

Da Silva Junior, J. N., Kons, R. L., Dellagrana, R. A., & Detanico, D. (2018). Injury prevalence in Brazilian jiu-jitsu athletes: Comparison between different competitive levels. *Rev Bras Cineantropometria e Desempenho Hum, 20*(3), 280–289. https://doi.org/10.5007/1980-0037.2018v20n3p280.

Gabbe, B. J., Finch, C. F., Bennell, K. L., & Wajswelner, H. (2003). How valid is a self reported 12 month sports injury history? *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsm.37.6.545.

das Graças, D., Nakamura, L., Barbosa, F. S. S., Martinez, P. F., Reis, F. A., & Oliveira-Junior, SA de (2017). Could current factors be associated with retrospective sports injuries in Brazilian jiu-jitsu? A cross-sectional study. *BMC Sports Sci Med Rehabil*. https://doi.org/10.1186/s13102-017-0080-2.

Harris, P. A., Taylor, R., Thielke, R., Payne, J., & Nathaniel Gonzalez, J. G. C. (2009). Research electronic data capture (REDCap) – a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics, 42*(2), 377–381.

IBJJF Graduation System. (2015). https://ibjjf.com/wp-content/uploads/2016/11/20150210_GraduationIBJJF_EN_vs2.pdf.Published. (Accessed 28 May 2019).

James, L. P., Haff, G. G., Kelly, V. G., & Beckman, E. M. (2016). Towards a determination of the physiological characteristics distinguishing successful mixed martial arts athletes: A systematic review of combat sport literature. *Sports Medicine, 46*(10), 1525–1551. https://doi.org/10.1007/s40279-016-0493-1.

Jensen, A. R., Maciel, R. C., Petrigliano, F. A., Rodriguez, J. P., & Brooks, A. G. (2017). Injuries sustained by the mixed martial arts athlete. *Sport Health, 9*(1), 64–69. https://doi.org/10.1177/1941738116664860.

Kreiswirth, E. M., Myer, G. D., & Rauh, M. J. (2014). Incidence of injury among male brazilian jiujitsu fighters at the world jiu-jitsu No-Gi championship 2009. *Journal of Athletic Training*. https://doi.org/10.4085/1062-6050-49.1.11.

Machado, A. P., Machado, G. P., & De Marchi, T. (2012). A prevalência de lesões no Jiu-Jitsu de acordo com relatos dos atletas participantes dos campeonatos mundiais em 2006. *ConScientiae Saúde*. https://doi.org/10.5585/conssaude.v11n1.3033.

McDonald, A. R., Murdock, F. A., McDonald, J. A., & Wolf, C. J. (2017). Prevalence of injuries during Brazilian jiu-jitsu training. *Sports, 5*(2), 39. https://doi.org/10.3390/sports5020039.

Pocecco, E., Ruedl, G., Stankovic, N., et al. (2013). Injuries in judo: A systematic literature review including suggestions for prevention. *British Journal of Sports Medicine, 47*, 1139–1143. https://doi.org/10.1136/.

Podcast, T. G. C. (2017). Episode 012: Dr. Chris moriarty.. https://grapplingcentral.com/episode-012-dr-chris-moriarty-2/.

Reis, F. J. J., Dias, M. D., Newlands, F., Meziat-Filho, N., & Macedo, A. R. (2015). Chronic low back pain and disability in Brazilian jiu-jitsu athletes. *Physical Therapy in Sport*. https://doi.org/10.1016/j.ptsp.2015.02.005.

Results - IBJJF. http://ibjjf.com/results/. (Accessed 15 October 2018).

Rule Book: General competition guidelines. *Competition format manual*, (2015). http://ibjjf.com/wp-content/uploads/2015/04/RulesIBJJF_v4_en-US.pdf.Published. (Accessed 9 September 2018).

Sanzarello, I., Merlini, L., Rosa, M. A., et al. (2016). Central sensitization in chronic low back pain: A narrative review. *Journal of Back and Musculoskeletal Rehabilitation, 29*(4), 625–633. https://doi.org/10.3233/BMR-160685.

Scoggin, J. F., Brusovanik, G., Izuka, B. H., Zandee van Rilland, E., Geling, O., & Tokumura, S. (2014). Assessment of injuries during Brazilian jiu-jitsu competition. *Orthop J Sport Med*. https://doi.org/10.1177/2325967114522184.

Snook, H. S., Webster, B. S., McGorry, R. W., Fogelman, M. T., & McCann, K. B. (1998). The reduction of chronic nonspecific low back pain through the control of early morning lumbar flexion: A randomized controlled trial. *Spine, 23*(23), 2601–2607. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed4&NEWS=N&AN=1999002651.

Snowden, J. (2018). *UFC 1, 25 Years later: The story behind the event that started an industry*. https://bleacherreport.com/articles/2804552-ufc-1-25-years-later-the-story-behind-the-event-that-started-an-industry.Published. (Accessed 27 May 2019).

Usuki, H., Rosen, A., Jawed-Wessel, S., Grandgenett, N., & McGrath, M. (2017). Injury history, severity, and medical care for athletes participating in Brazilian jiu-jitsu. *Journal of Athletic Training, 52*(6), 2017.

Weisenthal, B. M., Beck, C. A., Maloney, M. D., DeHaven, K. E., & Giordano, B. D. (2014). Injury rate and patterns among crossfit athletes. *Orthop J Sport Med*. https://doi.org/10.1177/2325967114531177.