ASSESSMENT OF COGNITIVE PERFORMANCE IN MIXED MARTIAL ARTS ATHLETES

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Incidents and awareness of sports-related concussion have grown in recent years, attracting attention in both the academic and popular press. These concussions can lead to the rapid onset of neurological dysfunctions, as well as a variety of subjective symptoms. Although concussive sequelae are typically considered transient, debate remains about the persistent effects of repeated traumatic contact during sport participation. Although research has examined the complications of head trauma found in traditionally popular sports (e.g., football, soccer, boxing), little research has focused on the growing sport of mixed-martial-arts (MMA). Research specifically pertaining to MMA is in nascent stages, but to-date studies suggest that concussive injuries for this sport are prevalent and the training regimens of these athletes may place them at a high risk for concussive or subconcussive head traumas—as well as the accompanying neurological difficulties. The current study is the first to assess cognitive profiles of MMA athletes using an objective neuropsychological assessment instrument. Among 56 athletes (28 MMA athletes and 28 athletes not exposed to head traumas), no neuropsychological differences were found between groups of athletes. Additionally, no aspects of MMA training regimen shared a reliable relationship with neuropsychological performance or subjective concussive symptoms. This suggests non-professional participation in MMA may not typically pose a significant risk for cumulative concussions and associated adverse neuropsychological consequences.

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CHAPTER 1

INTRODUCTION

Incidence and awareness of sports-related concussion has grown over the past two decades (Bailes, 2009), taking precedence as a key area of discussion across various sports on both national and international levels (e.g., Aubry et al., 2002, McCrory, Johnston et al., 2005; McCrory et al., 2009). Concussions occur as a result of biomechanical forces to the brain (Bailes, 2009; Majerske et al., 2008; McCrory, Johnston, Mohtadi, & Meeuwisse, 2001), that may or may not include temporary loss of consciousness, altered mental status, as well as a series of neurologic dysfunctions that lead to physical, metabolic, and physiological changes (Aubry et al., 2002; Bailes 2009; Giza & Hovda 2001). Although concussions have complex metabolic and physiological sequela, they are a well-recognized clinical phenomenon (Giza & Hovda, 2001), with diagnoses typically given based on functional status and subjective symptoms (Hunt & Asplund, 2010) that include somatic, cognitive, and neuropsychological components (Piland, Motl, Ferrara, & Peterson, 2003).

Concussions are predominantly considered to be transient in nature, and although the reported findings vary regarding the duration of concussive effects, most research suggests that the majority of concussive symptoms resolve within a few days of initial injury (e.g., Bleiberg, 2004; Collins et al., 1999; Macciocchi, Barth, Alves, Rimel, & Jane, 1996; McCrea, 2001). Unfortunately, similar agreement has not been reached regarding the persistent effects that result from cumulative concussions. While some research has suggested that persistent neurological effects are unlikely (e.g., Brown, Guskiewicz, & Bleiberg, 2007; Bruce & Echemendia, 2009; Iverson, Brooks, Lovell, & Collins, 2006; Macciocchi, Barth, Littlefield, & Cantu, 2001), others have found persisting effects (e.g., Collins et al., 1999; Iverson, Gaetz, Lovell, & Collins, 2004;

Moser, Schatz, & Jordan, 2005). Although it is not clear as to why there is a mixed literature regarding the neurocognitive effects of cumulative concussions, it is well agreed upon that appropriate post-concussive care is critical to managing incidents of sport-concussion, and this topic has assumed a central role in the sport-concussion literature (e.g., Aubry et al., 2002, Creighton, Shrier, Schultz, Meeuwisse, Matheson, 2010; McCrory, Johnston et al., 2005, McCrory et al., 2009).

Interest in sport-related concussion has grown in the past two decades, in both academic literature as well as popular press (Bailes, 2009; Randolph & Kirkwood, 2009). Much of this interest has been directed at the popular sport of football (Moser, 2007). Research utilizing football athletes has provided valuable information on sport-concussion, including estimated recovery times, as well as the risks of cumulative injuries (e.g., Guskiewicz et al., 2005; Theriault, De Beaumont, Tremblay, Lassonde, & Jolicoeur, 2010). Additionally, football players often comprise a large majority of the samples among sport concussion studies (e.g., Collins et al., 2003; Iverson, Brooks, Lovell, & Collins, 2006; Majerske et al., 2008; McCea et al., 2009), particularly in studies suggesting neuropsychological testing as a cornerstone for concussion management (e.g., McCrory, Makdissi, Davis, & Collie, 2005; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006).

Although much of the interest in sports-related concussion has been directed at football, research pertaining to other sports has accumulated as well. For example, it has been suggested that male soccer players have a 50% chance of sustaining a concussion within a 10-year period of play, with females having a 22% chance (Barnes, Cooper, Kirkendall, McDermott, Jordan, & Garrett, 1998). Head traumas that occur in both amateur and professional levels of soccer are associated with cognitive impairments, and have been deemed a public health concern (Matser, Kessels, Lezak, Jordan, & Troost, 1999; Matser, Kessels, Jordan, Lezak, & Troost, 1998). This becomes even more troubling given that soccer is considered the most popular and widespread sport throughout the world (Rutherford, Stephens, & Potter, 2003).

Rugby has also received attention from sport-concussion research, given its increasing rate of worldwide participation (Hollis et al., 2009). It has been suggested that rugby athletes, like their American football counterparts, are at an increased risk for neurocognitive deficits as a result of frequent sport-related head trauma (Shuttleworth-Rdwards & Radloff, 2008). Furthermore, this risk is inclusive of players at all levels (i.e., high school, adult professional, etc.). Unfortunately, injury risk may increase as a function of position, as players in positions that sustain more frequent contact have been found to perform worse on neurocognitive measures than players in positions with less frequent contact (Shuttleworth-Rdwards & Radloff, 2008). However, the risk for these athletes is buffered by appropriate safety precautions, for example, headgear, mouth protection, and careful monitoring of training time (Hollis et al., 2009)—safety buffers that extend to other contact sports as well (e.g., Jako, 2002). In addition to the invaluable findings obtained by investigations into football, rugby, and soccer, research has found that sports concussion is problematic for athletes across a range of sports from those playing ice hockey, to those racing horses (Koh, Cassidy, & Watkinson, 2003; Wall et al., 2006).

In conjunction with the growing attention paid to sports concussion, interest has also grown in methods of assessing these injuries. Although neuroimaging techniques are seldom useful in detecting concussive sports injury, the sensitivity offered by neuropsychological tests has established these techniques as a cornerstone in concussion management (Bailes, 2009; Guskiewicz et al., 2003; McCrory, Johnston et al., 2005; McCrory, Makdissi, et al., 2005). Furthermore, neuropsychological tests alleviate the reliance of self-report, which has been noted as a major difficulty in detecting the presence of concussive injury (McCrory, Makdissi, et al., 2005). Although various domains of cognitive functioning may be affected and assessed following concussive injuries, there is no single "best" method to evaluate them. Therefore, it is suggested that multiple domains be assessed in efforts to detect cognitive deficits, with particular attention being paid to measures of attention and concentration, cognitive processing, learning and memory, working memory, executive functioning, and verbal fluency (Grindel, Lovell, & Collins, 2001; Guskiewicz et al., 2004).

Whether it is in part due to, or despite, its violent nature, combat and fighting sports have appealed to athletes and audiences throughout history (Heilbronner et al., 2009). Although some organizations have suggested these sports be banned—the British Medical Association in particular (White, 2007), the frequent occurrence of head trauma found in a sport such as boxing offers a unique opportunity to assess neuropsychological effects that result from repeated, subconcussive blows to the head (Moriarty et al., 2004; Ravdin, Barr, Jordan, Lathan, & Relkin, 2003). Head injuries that result from boxing have been estimated to occur in up to 20% of boxers (Jordan, 2000), and are known to have a variety of neurocognitive sequela including chronic traumatic encephalopathy, neuropathologic injury, as well as long-term cognitive impairment (e.g., Clausen, McCrory, & Anderson, 2005; Moriarty et al., 2004).

While some research has suggested that these injuries are uncommon in amateur boxing (Jordan, 2000; Loosemore, Knowles, & White, 2008), opposing research has suggested that amateur boxers do show neurocognitive evidence of chronic injury (Clausen et al., 2005). Although individual studies may yield differing opinions on the safety of amateur boxing, recent large-scale reviews have suggested that under appropriate safety precautions (e.g., Clausen et al., 2005; Jako, 2002), there is no strong association between chronic brain injuries and amateur boxing (Loosemore et al., 2008). Despite the disagreement of whether boxers are vulnerable to long-term effects of concussive injury, one finding that is certainly troubling is that over half their injuries are cerebral in nature (Porter & O'Brien, 1996). Furthermore, traumas that occur during training may be the biggest concern for these athletes (Ravdin, Barr, Jordan, Lathan, & Relkin, 2003).

Mixed-martial-arts (MMA) differs from Western boxing in that while it is a full-contact fighting sport, it also includes elements of other martial art disciplines, including Thai boxing, submission wrestling, judo, and others. Since its American debut in the early 1990's (Ngai, Levy, & Hsu, 2008), MMA has become a pop-culture phenomenon (Wertheim, 2007), showing increases in both popularity and participation. Accompanying this popularity has been a surge of facilities and gyms that offer MMA training.

Unlike traditional boxing, which uses 8-10oz protective gloves, the gloves worn by MMA athletes weigh only 4oz (Nevada Department of Business and Industry, 2010), and therefore offer significantly less protection to competitors. With this difference in equipment, it is possible that the cerebral injuries and concussions that account for half of the injuries in boxing (Porter & O'Brien, 1996) may be even higher in MMA athletes. In fact, traumatic head injury was the reason that approximately 1/3 of televised matches was stopped over a 10-year period (Buse, 2006). Like boxing, the injuries that are sustained during training may be even greater (Ravdin et al., 2003), as the number of days that MMA athletes spar during the week has shown to be associated with their number of head injuries (Heath & Callahan, 2011). Given that MMA athletes typically train between 3–12 times per week and spar for approximately an hour per day (Amtmann, 2008; Heath & Callahan, 2011), their training routines alone may place them at risk for concussive trauma, regardless of whether they actually compete in the sport (Heath & Callahan, 2011).

Although concussive head traumas entail a variety of postural deficits, neurological, metabolic, and physical symptoms (e.g., Guskiewicz et al., 2001; Lovell et al., 2006), the symptoms are typically both benign and transient, often resolving in a few days (e.g., Bleiberg et al., 2004; Collins et al., 1999; Macciocchi et al., 1996). However, this resolution assumes appropriate medical management, with the primary focus of care being an athlete's absence from sport participation while symptomatic (e.g., Aubry et al., 2002; McCrory, Johnston et al., 2005; McCrory et al., 2009). Unfortunately, a vast majority of MMA athletes do not seek medical attention for traumatic head injuries, nor do they allow appropriate recovery time (Heath & Callahan, 2011). Additionally, many MMA athletes who seek medical treatment will forgo advice to refrain from training to heal, in favor of returning to their sport (Roy & Smith, 2010).

In light of the existing literature, mixed-martial-artists appear to be a unique and vulnerable population of athletes; both participants as well as proponents of the sport stand to benefit from research that expands previous sport-concussion literature to these specific athletes. Therefore, the aim of the current study was to more closely examine the relationship between MMA participation and cognitive performance. Specifically, this investigation sought to examine (a) whether MMA athletes show performance differences on an objective, standardized neuropsychological task in comparison to a group of individuals who are not exposed to full-contact sparring/striking after controlling for general intellectual functioning, and (b) whether there is a relationship between cognitive performance and MMA training routines. To address these goals, mixed-martial-artists and a comparison athlete group completed a neuropsychological assessment and reported on their training regimen (e.g., length of training history, number of training days per week, length of training sessions, etc.). It was specifically hypothesized that, (1) mixed-martial-arts athletes would evidence significantly poorer performance on the neuropsychological task compared to the control group of athletes, (2) there would be a negative relationship between weekly sparring regimen and neuropsychological task performance, and (3) there would be a negative relationship between the length of time individuals have participated in mixed-martial-arts and neuropsychological task performance.

CHAPTER 2

REVIEW OF LITERATURE

Defining Concussion

Incidents and awareness of sports-related concussion/mild-traumatic brain injury (MTBI) has grown over the past two decades (Bailes, 2009). In 2001, the International Symposium on Concussion in Sport was held in conjunction with the International Olympic Committee Medical Commission. The purpose of the symposium was to improve the safety and health of athletes who suffered sport-related concussions, by addressing issues surrounding concussive injury (Aubry et al., 2002). The International Symposium met again in 2004 (McCrory, Johnston et al., 2005), and 2008 (McCrory et al., 2009), to revise, update, and disseminate their original assessment of sports concussion.

Obtaining a consistent and precise definition of a sports-related concussion has been difficult, as there is not a universally agreed on definition (Hunt & Asplund, 2010). Although the operational definition of concussion has slightly varied in the literature, the functional definitions that are used refer to comparable phenomenon. For example, Bailes (2009) cites the American Academy of Neurology's definition as, "any trauma induced alteration in mental status that may or may not include a loss of consciousness" (p. 196), while Giza & Hovda (2001) define concussion as "any transient neurologic dysfunction resulting from a biomechanical force" (p. 228). Considering common characteristics of concussions, the International Conference on Sport Concussion unanimously agreed to define it as, "complex pathophysiologic processes affecting the brain, induced by traumatic biomechanical forces" (Aubry et al., 2002, p. 6). The group then delineated common defining features of a concussion including that it may be caused by a blow that has "an 'impulsive' force to the head," that it has "rapid onset of short-lived impairment of neurologic function that resolves spontaneously," that it may result in "neuropathologic changes," that it "results in a graded set of clinical symptoms that may or may not involve loss of consciousness" with symptoms that resolve in a sequential course, and that structural abnormalities are not seen with neuroimaging (Aubry et al., 2002, p. 6).

Cause of Concussion

Concussions occur as a result of biomechanical impact that leads to accelerated and decelerated forces to the brain (Bailes, 2009; Majerske et al., 2008; McCrory, Johnston, Mohtadi, & Meeuwisse, 2001). These forces lead to the immediate release of neurotransmitters as well as ionic fluxes, resulting in metabolic and chemical changes in the brain including tissue strain, as well as vascular and neural disregularities that occur throughout various brain regions (Bailes, 2009; McCrory et al., 2001; Maroon et al., 2000). Hovda and colleagues (1995) considered the cellular changes that occur after a concussive injury to be a neurochemical and neurometabolic cascade of events. For example, neurotransmitter release mechanisms become dysfunctional at the extracellular and intracellular levels (Bailes, 2009). Cell membrane permeability becomes compromised, leading to an influx of chemical exchange that affects cellular metabolism and blood flow, ultimately depressing metabolic function (Hovda et al., 1995; Maroon et al., 2000). Axons and neurons are exposed to non-localized injury, which depending on the severity of the impact may be non-reversible (McCrory et al., 2001).

Despite having a complex physiological sequela, concussion is a well-recognized clinical phenomenon (Giza & Hovda, 2001). Individuals are typically given the diagnosis of concussion based on functional status, as well as physical and physiological symptoms that are experienced at the time of an injury (Hunt & Asplund, 2010). Common symptoms of concussions have been grouped into a 3-factor model, consisting of somatic symptoms such as headache, nausea, and dizziness, cognitive symptoms such as difficulty concentrating and feeling slowed down, and neuropsychological symptoms such as fatigue, drowsiness, and difficulty falling asleep (Piland, Motl, Ferrara, & Peterson, 2003).

Effects of Concussion

Associated with physical and physiological symptoms of concussion, are a myriad of neurological and postural/spatial difficulties. Assessing these difficulties is becoming commonplace for objective measurement when managing sport-related concussion (Guskiewicz, Ross, & Marshall, 2001). For example, recently concussed athletes have shown deficits in postural stability and balance, attributed to problems with sensory interaction and integration (Guskiewicz et al., 2001; Riemann & Guskiewicz, 2000). Guskiewicz et al. claimed that these deficits might lead to athletes' inability to exercise appropriate postural control under altered sensory conditions, thereby making them inefficient in executing rapid postural changes in response to various impacts. These postural stability deficits are most problematic and notable in the initial 2 days of sustaining a concussion, and although they often return to baseline levels within 3 to 5 days post-injury (Guskiewicz et al., 2001), may linger for extended periods of time (Geurts, Ribbers, Knoop, & van Limbeek, 1996).

In addition to postural deficits that occur as a result of concussive injury, neuropsychological deficits are also well documented. Among the most commonly reported are difficulties with attention, concentration, information-processing, and memory (e.g., Leininger, Gramling, Farrell, Kreutzer, & Peck III, 1990; Macciocchi, Barth, Alves, Rimel, & Jane, 1996). For example, Gronwall & Wrightson (1981) examined how these injuries affect neurological performance and concluded that memory deficits occur via three different mechanisms. The first mechanism was a deficit in information processing, specifically, complex processing or working under time constraints. The second mechanism involved deficits in encoding materials into long-term memory storage. The third mechanism, although seen less frequently, was a deficit in retrieving information stored into memory. Each of these functions of memory can be affected independently, as well as to variable degrees by concussive head traumas (e.g., Barth, Macciocchi, Giordani, Rimel, Jane, & Boll, 1983; Gronwall & Wrightson, 1981; Iverson, Brooks, Collins, & Lovell, 2006; Lezak, Howieson, & Loring, 2004).

In addition to the memory difficulties experienced with concussive injuries are deficits in reaction time. For example, MacFlynn, Montgomery, Fenton, and Rutherford (1984) administered a reaction time test to individuals experiencing closed-head injuries, and found poorer performance between these individuals and matched individuals not experiencing head injury. The differences were found within 24 hours of injury, and tend to resolve in variable timeframes, typically within a few days but possibly lasting up to 6 months (e.g., MacFlynn et al., 1984; Iverson et al., 2006; Warden et al., 2001). In addition to the injured individuals' slowed reaction time, they also evidenced significantly slow EEG recordings. It was concluded that difficulties in reaction times found in closed-head injury may be due to slowing of central processing systems, and that this may be one of the primary deficits in these types of head injuries (MacFlynn et al., 1984).

Duration of Concussive Effects

Although it is unequivocal that concussive head traumas bring about a series of physical, physiological, and neurological difficulties, questions regarding the duration of these impairments vary throughout the literature (Bleiberg et al., 2004). For example, Dikmen, McLean, and Temkin (1986) compared neuropsychological performance between individuals who had sustained head injuries 30 days prior, and those who had not. It was found that the injured individuals evidenced an overall trend towards slightly lower performance one-month after receiving a head injury compared to a control group, and that some differences continued to be significant at this time. However, one year after the injury there were no notable differences between the two groups.

Matser, Kessels, Lezak, Jordan, and Troost (1999) also examined the lingering effects of head injury by conducting a cross-sectional study of athletes to determine whether similar neuropsychological deficits exist in soccer players with a history of head insult when compared to dissimilar athletes. The authors found that a history of head trauma among athletes with an average career of 17 years was associated with impairments in areas of planning, memory, and fine motor skills when compared to a control group. It was concluded that concussions obtained over the course of a career could play a key role in the development of long-term cognitive impairment (Matser et al., 1999).

Although some research yields widely variable timeframes for concussion-related impairments, the number of these studies is small, and they often contain methodological issues or inconsistencies. These issues include, for example, the definition and classification of head injuries, biased participant selection, and a lack of control groups (Dikmen & Levin, 1993; Bleiberg et al., 2004). In contrast to these studies, is a body of research that has used more stringent methodological controls, and has found cognitive recovery to commonly occur between 2–10 days after injury (Bleiberg, 2004). For example, Macciocchi and colleagues (1996) compared the neurocognitive performance of college athletes receiving a single concussive injury at 24 hours, 5 days, 10 days, and 12 weeks post-injury to an age, gender, and education-matched control group. The head-injury group showed impaired performance immediately after their injury, but was essentially equivalent to their non-injured counterparts by day 5 post-injury, and lacked residual cognitive impairment (Macciocchi et al., 1996).

Collins et al. (1999) also found a five-day recovery period in a study that assessed risk factors associated with short and long-term outcomes of neurological performance. In their study, college football players received baseline neurocognitive evaluations, and were followed over approximately two years. Participants who subsequently received concussions were then matched to control athletes from the same sample and compared on a series of neuropsychological measures. The concussion group performed worse than the control group within 24 hours of their injury, but had comparable performances at 5 days post-concussion. It was concluded that a concussive head injury does not result in long-term cognitive deficit (Collins et al., 1999).

A short timeline for recovery was also found when assessing neurocognitive performance at regular intervals up to 14 days post-injury (Bleiberg et al., 2004). In this study, athletes were administered baseline neurocognitive testing, and were retested at 1 to 2, 3 to 7, and 8 to 14 days following concussive injury, and were compared to a non-concussed control group of participants from the same sample. Performance deficits were evident between the groups on the day of injury, as well as 1 to 2 days post-injury. However, recovery of neurocognitive performance was found during the 3 to 7 day assessment period–a finding comparable to previous research assessing the duration of concussive effects (Bleiberg et al., 2004).

In line with studies that suggest a short recovery period utilizing traditional neurocognitive assessments, McCrea (2001) reviewed the Standardized Assessment of

Concussion (SAC)—a well validated, brief, objective measurement for assessing the neurocognitive functions most commonly affected by concussion (e.g., orientation, working memory, delayed recall). This neurocognitive composite instrument found that immediately after concussive injury, concussed individuals evidenced performance deficits compared to non-concussed controls. Like previous studies suggesting a short time to baseline recovery, the performance deficits between these groups when assessed with this measure resolved by 48 hours post-injury (McCrea, 2001).

This body of research suggests that when more strict methodological controls are used to assess recovery times from concussive injury, for example, control groups, matched samples, clear injury definitions, etc., that cognitive recovery from single concussive episodes generally occurs in a 3 to 7 day timeframe post injury. This recovery includes a return to baseline functioning, as well as the presence of practice effects comparable to controls (Bleiberg, 2004).

Effects of Cumulative Concussion

Although it is generally agreed upon that the effects of a single concussion are transient and for the most part non-severe, the consensus on the repercussions of repeated traumas is not as clearly defined, and often yields differing conclusions. For example, Macciocchi, Barth, Littlefield, and Cantu (2001) conducted a study to determine whether neurocognitive performance differences could be detected between athletes experiencing either 1 or 2 concussions. Participants who sustained 1 and 2 concussive injuries were matched on characteristics such as age, education, and duration of sport competition, and administered a series of neuropsychological performance tests. The authors found that the neurocognitive performance of individuals who sustained 2 injuries did not differ from their single injury counterparts. Furthermore, the authors found that test performance of individuals that sustained two injuries was no different after their second injury than after their first. Additionally, the authors failed to find reliable differences between individuals who experienced their second concussion shortly after their first, versus in successive seasons. The authors concluded that receiving two concussive injuries separated by at least 2 weeks did not result in more neurocognitive impairments than receiving one injury. Although the authors highlighted the possibility that their lack of findings may have due to factors such as consistent severity ratings, variable times at which the injuries occurred, or sample characteristics, other research has yielded similar findings.

For example, Iverson and colleagues (2006) conducted a study to determine whether athletes with a history of zero, one, or two previous concussions would differ in neuropsychological test performance. Participants were stratified into their respective groups and administered a computerized neuropsychological test battery measuring aspects of cognitive function such as attention, processing speed, reaction time, etc. The authors did not find significant differences between the concussion groups for any of the performance measures. The researchers concluded that if cumulative effects exist from previous concussions, they are likely quite small (Iverson et al., 2006).

A similar study was carried out by Brown, Guskiewicz, and Bleiberg (2007) to determine the effects of various factors on baseline neuropsychological performance. Participants were stratified into one of two groups, on the basis of having either 0-1 concussions, or 2 or more concussions. Participants were administered the Automatic Neuropsychological Assessment Metrics (ANAM), an automated battery of subtests assessing a variety of neuropsychological constructs. The authors found that no differences were found between concussion groups on any of the subtest scores.

Furthermore, Bruce and Echemendia (2009) suggested the possibility that previous studies which failed to find a relationship between concussive history and neurocognitive performance may been due to the variety of assessments being used, as opposed to a distinct lack of relationship. Therefore, they assessed neurocognitive performance by using a combination of traditional neuropsychological tests, as well as computer-based neuropsychological tests, in athletes reporting 0, 1, 2, or 3 or more concussions. In line with previous research that failed to find neurocognitive deficits as a result of multiple concussions, performance on either traditional neuropsychological measures or computerized measures was not associated with a history of multiple concussions. The authors concluded that a history of multiple concussions bore little to no impact on long-term neurocognitive functioning.

Although the notion that long-term neuropsychological deficits would not be markedly apparent in individuals with a history of multiple concussions seems counter-intuitive, this finding does exist in the literature, and has been suggested by multiple investigators. However, contradictory findings have also been well documented, providing support for the more intuitive notion, that experiencing cumulative concussions is related to neurocognitive deficits that persist beyond the transient nature of the injury.

For example, Collins et al., (1999) conducted a multisite study to assess the relationship between concussion history and baseline neuropsychological performance in college football players. Athletes were grouped on the basis of having no concussive history, a single concussion history, or a history of 2 or more concussions, and were administered a test battery to assess multiple aspects of neurocognitive performance. The authors found that concussive history was associated with long-term deficits in areas of executive functioning and information processing speed for individuals who had experienced 2 or more concussions. However, these deficits were not apparent for the single concussion group (Collins et al., 1999).

Similar results were found in a study of youth athletes, (Moser, Schatz, & Jordan, 2005). Athletes were once again categorized on the basis of having a single or non-existent concussive history, a history of two or more concussions, or having recently experienced a concussion, and administered neuropsychological assessments over a variety of cognitive domains. The authors found that young athletes who had previously sustained two or more concussions resembled young athletes who sustained a concussion in the past week, unlike the athletes with a history of zero or one concussions, and concluded that effects from multiple concussions can endure (Moser et al., 2005). Similar research highlighting the enduring effects of concussion in young athletes has been established in studies using significantly smaller samples (Moser & Schatz, 2002), potentially highlighting the magnitude of this relationship.

Research has also examined complications that exist as a result of cumulative concussions, above and beyond the neurocognitive deficits that are found. Iverson, Gaetz, Lovell, and Collins (2004) conducted a study that matched athletes with a history of three or more concussions to athletes having no prior concussions, and administered measures of neurocognitive functioning and medical complications during a baseline and a post-injury phase. Not only did the authors find that athletes having multiple concussions displayed lower neurocognitive baseline performances than did their non-concussed counterparts, but they also experienced more adverse consequences during the acute recovery phase, and displayed worse markers of severity following subsequent concussions. Specifically, the three-concussion group was significantly more likely to experience amnesia and disorientation.

Returning to Play

Although researchers are not clear on the reasons behind the mixed literature regarding the neurocognitive effects of cumulative concussions, they are in agreement that appropriate post-concussive care should be implemented to avoid the potential hazards that can arise from experiencing multiple concussions (e.g., Aubry et al., 2002; McCrory, Johnston et al., 2005; McCrory et al., 2009). A primary concern of post-concussive care with athletes is deciding when they are fit to resume sport participation. This decision is commonly aided by following what is often referred to as "return-to-play" guidelines, which serve to ensure that adequate time has passed since the injury, and that the athlete has returned to a pre-injury state of functioning. Return-to-play considerations are heavily emphasized in concussion literature, as improper post-concussive care (including repeat concussions) can potentially lead to serious consequences such as death or severe, permanent disability—including cerebral edema, or chronic traumatic encephalopathy (Bailes, 2009; McCrea et al., 2009).

Return-to-play decisions and the potential consequences they seek to avoid are becoming increasingly important when considering that the risk of a repeat concussion is increased during the immediate days following an initial concussion. McCrea and colleagues (2009) highlighted this finding in a study that sought to determine the influence of a symptom free waiting period on risk of repeat injury after a sports-related concussion, using the largest sample of sport-related concussion athletes reported at the time. With respect to repeat concussions, the authors found that approximately 80% of these occur within 10 days of the primary concussion (McCrea et al., 2009). This finding was consistent with previous studies suggesting a window of vulnerability for repeat concussions immediately following an initial concussion, that decreases as time passes and symptoms resolve (Giza & Hovda, 2001; Guskiewicz et al., 2003).

Although researchers agree that return-to-play decisions have a critical role in concussion management and sports medicine practice, there is often confusion about the best approach to making them, which stems from the lack of a systematic decision making model that integrates all of the relevant factors to the decision (Creighton, Shrier, Shultz, Meeuwisse, & Matheson, 2010). To this end, Creighton and colleagues (2010) developed a 3-step "decision-based" model, aimed at clarifying factors to be considered in return-to-play decisions.

The first step of their decision-making process is referred to as "Evaluation of Health Status," which requires an assessment of multiple domains, including biological, psychological, as well as medical factors. The primary purpose of this step is to evaluate where the athlete stands at the current time relative to how he or she would be normally. Factors assessed in this step include symptoms, functional test results, lab test results, as well as the potential seriousness of the injury.

The results from this step are heavily weighted into the second step of the process, which is referred to as "Evaluation of Participation Risk." This step serves to evaluate the risk of returning an athlete to play, and precedes the ultimate decision of whether or not to do so. Here, factors such as the level of collision in the sport, the position played, the level of competition, and athletes' abilities to protect themselves (e.g., padding) are considered. Although these factors are not directly related to evaluating the health status of an athlete (step 1), they are directly associated with the particular injury in question, and therefore can play a large role in either increasing or decreasing the risks involved in returning to play—given where an athlete stands in terms of their health status. This step is important in that it places the nature of both the athlete and their injury in a specific context to better make an informed decision. The authors provide the example of a recreational athlete's risk from an injury when compared to the risk of an

Olympic athlete, or the differences in risk between a swimmer and a football player with the same injury (p. 380).

The third step of the model is referred to as “Decision Modification.” Here, consideration is given to factors that may change the ultimate return-to-play decision that would have been made as a direct outcome of step 2, Evaluation of Participation Risk. Although the authors highlight that some may argue the only consideration in returning an athlete to play should be the risk taken by doing so, all sports entail some degree of risk. Therefore, this step presents factors to consider when determining an acceptable level of risk in a particular situation. This step includes an assessment of factors such as the timing of the injury (e.g., playoffs or exhibition), pressures from an athlete (e.g., their desire to compete), and conflicts of interest (are there financial or occupational ramifications if an athlete is withheld from competition).

The window of vulnerability for a repeat concussion is most prominent in the days immediately following an initial concussion (McCrea et al., 2009). Given this vulnerability, along with the potential consequences it entails (e.g., Bailes, 2009; McCrea et al., 2009), return-to-play guidelines have assumed a central role in concussion management (e.g., Creighton et al., 2010, McCrory et al., 2009), and advice on when athletes can safely resume participation is included in the treatment of all injuries (Creighton et al., 2010). At the current time, there is not an empirically based protocol or model for deciding when an athlete can resume sport participation, and return-to-play criteria will vary from setting to setting (Creighton et al., 2010; Hunt & Asplund, 2010; Johnston, McCrory, Mohtadi, & Meeuwisse, 2001). However, the Decision-based model offers a structure that includes the conscious and subconscious factors to be considered by clinicians and treatment professionals when making important return-to-play decisions (Creighton et al., 2010).

Sport-Specific Research

The interest in sport-related concussion has grown over the past two decades, in both the academic literature as well as the popular press (Bailes, 2009; Randolph & Kirkwood, 2009). Although research in sport concussion often focuses on the nature of a concussion itself by looking at factors such as recovery time, symptomatology, etc., there is also literature that focuses on the vulnerabilities to concussive injury found in specific sports. Even though football is the most frequently studied sport among those in sport concussion literature (Moser, 2007), a growing body of research is taking an interest in other contact sports as well. Koh, Cassidy, and Watkinson (2003) reviewed a 15-year span of sport concussion literature to estimate the incidence of concussion in various contact sports, and found that football and ice hockey had the highest incidence of concussion among high school, college, and amateur sports (Koh et al., 2003).

Research has also suggested that specific sports (e.g., rugby, soccer) inherently contain high occurrences of repeated subconcussive impacts that can make athletes especially vulnerable to the sequela of sport concussion. For example, Matser, Kessels, Lezak, Jordan, and Troost (1999) examined whether soccer-related concussions and the subconcussive impacts that result from athletes' hitting the ball with their head would put this population of athletes at risk for chronic traumatic brain injury. The authors concluded that the traumas incurred by participating in soccer at the amateur level were associated with impaired cognitive performance in memory and planning tasks. The authors found similar results when studying professional soccer players (Matser, Kessels, Jordan, Lezak, & Troost, 1998) and concluded that the chronic brain injuries that can arise from routine soccer play are a public health concern (Matser et al., 1999). Similar research on the vulnerabilities of soccer athletes found that male soccer players have a 50%

chance, and female soccer players have a 22% chance of sustaining a concussion within a 10-year period of playing soccer (Barnes, Cooper, Kirkendall, McDermott, Jordan, & Garrett, 1998). The authors concluded that concussions are a frequent hazard in soccer, a finding that becomes even more troubling considering that soccer is considered the world's most popular and widespread sport (Rutherford, Stephens, & Potter, 2003).

Rugby is also a sport that has received attention, given both the increasing rates of participation throughout the world (Hollis et al., 2009), and the elevated risk of repeated subconcussive, or mild traumatic brain injuries (Shuttleworth-Rdwards & Radloff, 2008). In order to study the residual effects of concussion amongst rugby players, Shuttleworth-Rdwards & Radloff (2008) conducted neurocognitive testing on these athletes during a pre-season period. The authors highlighted the pre-season period as being optimal for studying residual effects, in that the athletes would not have been playing the sport for approximately four to five months, and would therefore present without the acute effects of recent concussions. Both rugby athletes and non-contact control athletes were chosen at various levels of competition including high school, youth national team (i.e. under 21 years of age), and open national team (i.e. over 21 years of age) and given a series of neurocognitive assessments focusing on visuomotor processing speed. The study found that rugby players performed worse than their control-athlete counterparts on all tasks. The authors also failed to find significant relationships between age and task performance, and suggested that the neurocognitive deficits found in rugby players exist at all levels of the sport (i.e. high school, youth competitive, adult competitive). In addition to the findings contrasting rugby athletes to controls, analyses also compared the neurocognitive performance of forward position players—who are more exposed to cerebral injury, with backline position players—who are less exposed to cerebral injury. The authors found that the forward position players performed more poorly than their backline counterparts, and suggested that within a particular sport, athletes in certain positions are especially vulnerable to specific neurocognitive deficits.

As rugby is a growing sport, especially at amateur/nonprofessional levels (Hollis et al., 2009), research has sought to identify factors that may protect against brain injury for these athletes. For example, Hollis et al. (2009) administered surveys to a large sample of nonprofessional rugby players to determine the role of factors such as training patterns, use of protective equipment, history of concussion, etc., in exposure to sports-related concussive injuries over a subsequent period ranging from 1 to 3 years. The authors found that players under the age of 21 were nearly twice as likely to experience concussive injury—which may have been in part because many players in this age group had recently moved up to a higher level of competition where they faced larger, more skilled, and faster opponents. It was also found that inexperienced players (0–3 years) and very experienced players (8+ years) had a higher incidence of concussive injury, as did players who infrequently wore headgear and mouth protection, trained for less than 3 hours per week, had higher personality impulsivity scores, and as expected, had a previous history of injury. The authors concluded that even in non-professional rugby the incidence of brain injury was high, but that proper safety equipment and concussion management could reduce future injuries.

Neurological Assessment

With the growing interest and resources that have been directed at sport related concussion, neuropsychological testing has become recognized as a critical component in managing concussions by international sports organizations, researchers, and practicing sports medicine physicians (e.g., Bailes, 2009; McCrory, Johnston et al., 2005; McCrory, Makdissi, Davis, & Collie, 2005). A primary reason these tests have become so important to concussion management is because they are sensitive to changes that occur as a result of sport-related concussions, whereas neuroimaging techniques (e.g., computer tomography [CT scan], magnetic resonance imaging [MRI], x-ray) often fail to show abnormalities following these injuries (Bailes, 2009; Guskiewicz et al., 2004; McCrory, Johnston, et al., 2005). Although it should be noted that some neuroimaging techniques can detect these changes—particularly in more severe injuries (e.g., functional magnetic resonance imaging [FMRI])—these methods are often impractical in sport contexts due to cost and availability issues, and are rarely utilized in the assessment of common sport concussions (Bailes, 2009).

Another reason that neuropsychological tests have gained favor in concussion management is their alleviation of a major difficulty in determining the presence of a concussion—reliance on subjective self-reporting (McCrory, Makdisi, et al., 2005). An athlete's self-report of concussive symptoms is often based on various factors, such as the rapport between the athlete and examiner, as well as their desire to return to sport participation (e.g., Creighton et al., 2010; Hunt & Asplund, 2010). These factors are often influenced by the athletes perceived need to resume participation for reasons such as pressure from coaches/teammates, job security, incentives, internal motivations, etc. (Creighten et al., 2010), as athletes are "often known minimize the severity of their symptoms to remain on the active roster" (Barr, 2001, p. 297). This self-report bias serves as one of the primary reasons that concussion prevalence is often underreported and underrepresented (Grindel, Lovell, & Collins, 2001).

As neuropsychological testing becomes more prominent in sports assessment and concussion management, computerized testing has gained particular favor as technological advances have occurred in recent years. Traditional neuropsychological testing (i.e. paper and pencil tests) is limited because its administration and interpretation require trained personnel, such as neuropsychologists, and because it is time consuming and costly to administer to large groups, or entire teams of athletes (Collie & Maruff, 2003). Furthermore, it has been suggested that computerized neuropsychological tests may be more sensitive to mild concussion sequela than traditional tests, while offering better detection of performance variability (Collie, Darby, & Maruff, 2001). Additionally, computerized tests offer a variety of practical advantages such as ease and standardization of administration, increased sensitivity in measurement, the ability to assess large numbers of athletes in short periods (approximately 20 minutes), computerized analysis that can identify subtle changes, the availability of multiple forms to reduce practice effects, and the ease of yielding rapid results (Collie et al., 2001; Guskiewicz et al., 2004).

As the use of neuropsychological testing has grown, two primary methods of testing have emerged with straightforward rationales (Guskiewicz et al., 2004; McCrory, Makdissi et al., 2005). The first method uses testing following the subjective resolution of concussion symptomatology, since it is well agreed that athletes should not resume sport participation while symptomatic. With this method, an athlete's neurocognitive performance following a concussion can be compared to his or her own baseline performance, or norm groups. This allows for the detection of injury markers via cognitive deficits that may exist beyond the resolution of subjective symptoms. The second method involves testing at fixed time points (e.g., day 1, day 3, day 7), and is useful to track post-injury recovery. This method is especially useful beneficial in the absence of baseline performance, as it can help determine when a stable level of neurocognitive performance has been achieved, and presumably reached a baseline level (Barr, 2001; Guskiewicz et al., 2004).

Although many domains of cognitive functioning may be affected and assessed following sport-concussion, there is no single "best" test to use when evaluating sport concussion. Therefore, using multiple measures gives the benefit of assessing for a wide range of cognitive deficits that may be present (Grindel, et al., 2001; Guskiewicz et al., 2004). Comprehensive batteries often include measures of attention and concentration, cognitive processing, learning and memory, working memory, executive functioning, and verbal fluency (Guskiewicz et al., 2004). Technological advances have led to the development of various computerized neuropsychological tests, each having its own strengths and emphasis (e.g., Collie et al., 2001; McCrory, Makdissi, et al., 2005). Grindel and colleagues (2001) suggest that as technological advances progress, not only will computerized assessment continue becoming more effective in evaluating concussion, but will also offer functional tests of an athlete in game/event-like situations as a further evaluation of performance and readiness to return (Grindel, Lovell, & Collins, 2001).

Fighting Sports

Boxing

Whether it is in part due to, or despite, its violent nature, combat/fighting sports have appealed to both athletes and audiences throughout history (Heilbronner et al., 2009). Because of this violent nature, the British Medical Association has called for a ban of these sports (White, 2007). However, the frequent occurrence of head trauma found in the sport of boxing provides a unique opportunity to assess the neuropsychological effects that result from repeated, subconcussive blows to the head (Moriarity et al., 2004; Ravdin, Barr, Jordan, Lathan, & Relkin, 2003). The head injuries that result from professional boxing are known to have a variety of possible neurocognitive sequela for participants, including chronic traumatic encephalopathy, neuropathologic injury, as well as cognitive impairment (e.g., Clausen, McCrory, & Anderson, 2005; Moriarty et al., 2004). In fact, chronic traumatic brain injuries associated with boxing have been estimated to occur in as many as 20% of professional boxers, and are considered a "major public health concern." (Jordan, 2000, p. 8). Some research has suggested that these injuries are not frequently found in amateur boxing, given both the limited exposure of these athletes to the sport (Jordan, 2000; Loosemore, Knowles, & White, 2008), as well as safety precautions that serve as buffers to serious injury (e.g., universal rules, shorter bouts, scoring of points as a primary objective as opposed to knocking out an opponent, mandatory use of headgear, etc.) (e.g., Jako, 2002). However, there is some controversy regarding the conclusive safety of amateur boxing, as some researchers have stated that these athletes do show neurological evidence of chronic traumatic brain injury (Clausen et al., 2005). Additionally, over half of the injuries found amongst amateur boxers are cerebral in nature (Porter & O'Brien, 1996).

Although there is no conclusive evidence regarding the risk factors and injuries from boxing (Heilbronner et al., 2009; Zazryn, Cameron, & McCrory, 2006), significant research has emerged in the last few years on amateur boxing as a sport, as well as the neurological effects that ensue (Heilbronner et al., 2009). A study employing a control-group design (Porter & Fricker, 1996) sought to detect a relationship between amateur boxing and brain injury, by using a 15-18 month prospective design of active boxers, and controls who trained at the same gym but did not spar or compete. The primary finding of the study was that the only poor performance by active competition group compared to the control group was on a finger-tapping test of the dominant hand. The researchers suggested that although this discrepancy may be due to central neurological deficits, given that it occurred at both baseline and follow-up assessments, the more plausible explanation was that it was due to cumulative minor trauma to the hands. The authors concluded that there was not evidence of neuropsychological impairment in amateur boxers compared to their control counterparts. Furthermore, a similar study was conducted using a 9-year prospective design (Porter, 2003) to assess whether neurocognitive deteriorations would occur in amateur boxers over a longer timeline. This longer study found comparable results to its predecessor with the shorter timeframe, and it was concluded that there was no evidence of decreased neurocognitive performance over a 9-year window, and that these deficits may not exist in amateur boxers (Porter, 2003).

One important consideration of amateur boxing is the context in which competition occurs. Competition is typically a tournament style event, where competitors may participate in several bouts over a short period, such as days or weeks, which may result in acute cognitive dysfunction (Moriarity et al., 2004). To assess this possibility, Moriarity and colleagues conducted the first study to prospectively assess cognitive performance of amateur boxers who did not receive concussions during a tournament style event, by administering a computerized neurocognitive performance test to competitors participating in one, two, and three bouts, and a non-boxing control group. None of the participants experienced a decline in performance from their baseline assessments on any of neuropsychological measures. However, there was a small group of athletes deemed as “high risk,” who either had nose bleeding during the course of their bouts, or had their bouts stopped by a referee. These competitors did show performance deficits in some neurological domains. The authors concluded that amateur/tournament style boxing does not in and of itself result in acute cognitive dysfunction except in situations where the bout is stopped by a referee, and, that assuming appropriate medical and safety procedures are taken there is little risk to boxers who participate in these tournaments (Moriarity et al., 2004).

In addition to individual studies, recent large-scale research reviews have also assessed the risk of brain injury as a result of amateur boxing. Specifically, Loosemore et al. (2008) noted that many studies suggesting negative effects from this sport were of a poor methodological quality, and lacked various important design characteristics such as control groups, adequate sampling procedures, and prospective approaches. Of additional importance, many of these studies failed to consider current safety standards and practices that have been implemented in recent years (e.g., Clausen et al., 2005; Jako, 2002). However, after reviewing previous research in light of these considerations, it was concluded that the current evidence does not yield a strong association between chronic brain injury and participation in amateur boxing (Loosemore, et al., 2008).

Although research has yielded varying conclusions regarding the presence and severity of neurological consequences of boxing at any level, (e.g., Clausen, et al., 2005; Moriarty et al., 2004; Jordan, 2000; Loosemore et al., 2008), it has been suggested that future generations of boxers will face significantly lower risk of brain injury than previous boxers (Clausen et al., 2005). A primary reason for this is changes that have occurred over time regarding the course of a boxers' career, as it bares relationship to the amount of head trauma that is sustained. Current boxers compete less than boxers in the past, as their total length of career, number of rounds fought, and number of matches fought have steadily declined over time, and should therefore reduce their incidence of brain injury (Clausen et al., 2005). Although Clausen noted these competition related declines, specific mention was made to the difficulty assessing exposure to head injury sustained during sparring, and that sparring may play an important role in chronic brain injury. Research has in fact suggested that sparring plays a critical role in exposure to head injury, and that more trauma is sustained during these training sessions than in actual competition (Ravdin et al., 2003). It is therefore certainly plausible that while boxers fight in fewer sanctioned matches, their exposure to sparring in between matches increases in service of maintaining physical readiness.

Mixed-Martial-Arts

Mixed-martial-arts (MMA) differs from Western boxing in that while it is a full-contact fighting sport, it also incorporates elements of other martial arts, including Thai boxing, submission wrestling, judo, and others. Since MMA began holding events in America as early as 1993 (Ngai, Levy, & Hsu, 2008), it has grown in both popularity and participation, to become a pop-culture phenomenon (Wertheim, 2007). With this growth, a surge of gyms and facilities that offer training in MMA has followed.

Unlike traditional boxing, which uses 8-10oz protective gloves, the gloves worn by MMA athletes weigh only 4oz (Nevada Department of Business and Industry, 2010), thereby offering significantly less protection to competitors. Although cerebral injuries and concussions account for over half of the injuries found in boxers (Porter & O'Brien, 1996), it is highly plausible that this number is even higher among MMA athletes given their more minimal glove protection. In fact, head trauma was the reason for stoppage in approximately 1/3 of televised MMA matches over a 10-year period (Buse, 2006).

Unfortunately, these injuries may not occur solely during competitive matches, as the damage sustained during sparring is suggested to be even greater (Ravdin et al., 2003). In fact, the number of days that MMA athletes spar during the week has been shown to have a positive relationship with their number of head injuries (Heath & Callahan, 2011). Considering that MMA athletes typically train between 3–12 times per week and spar for approximately an hour per day (Amtmann, 2008; Heath & Callahan, 2011) their training routines alone may place them at risk for concussive traumas, even if they are not active competitors in the sport (Heath & Callahan, 2011). This research also found that approximately 15% of MMA athletes experienced a knockout (a period of defenselessness and non-responsiveness) over the course of their training, and 30% experienced a technical knockout (also a period of defenselessness, but which includes partial responsiveness), with these injuries occurring an average of three times over the course of MMA participation. These traumas are known to bring a rapid onset of various neurological dysfunctions, physical and/or physiological symptoms, as well as postural deficits (Guskiewicz et al., 2001; Lovell et al., 2006).

Although concussive head traumas entail a variety of neurological, metabolic, and physical symptoms, these symptoms tend to be both benign and transient, as they often resolve in a matter of days (e.g., Bleiberg et al., 2004; Collins et al., 1999; Macciocchi et al., 1996). However, this resolution assumes proper medical management, with the primary tenant of care being an athlete's absence from sport participation until they become asymptomatic (e.g., Aubry et al., 2002; McCrory, Johnston et al., 2005; McCrory et al., 2009). Unfortunately, a vast majority of MMA athletes do not seek medical attention for traumatic head injuries, nor do they allow adequate time for recovery (Heath & Callahan, 2011). Even more problematic is that many MMA athletes who do seek medical treatment will show noncompliance in favor of returning to their sport, rather than interrupting their training routines to complete the healing process (Roy & Smith, 2010). These lines of research suggest that mixed-martial-arts athletes may be placing themselves at excessive risk for concussive head traumas, as well as the neurologic sequela that ensue—particularly from improper medical management.

CHAPTER 3

METHODS

Participants

Participants included 28 males who participate in full-contact mixed-martial-arts and 28 males who participate in exercise that does not involve full-contact striking (e.g., submission wrestling, high intensity interval training, judo, etc.). The mean age for the mixed-martial-arts athletes was 28.9 years (range = 19 - 58), which was nonsignificantly different from the comparison group of athletes who, on average, were 31.7 years (range = 23 - 51). Additionally, a measure of general intellectual functioning (the Shipley Institute of Living) suggested the athletes were also comparable in cognitive ability, as the MMA athletes scored comparably (M = 48, SD = 5.2) to the control athletes (M = 49, SD = 5.4).

Table 1 displays the mean, standard deviation, and range for the MMA athletes training routines, and the average number of knockouts and technical knockouts. As shown in the table, approximately 29% (n = 8) of the mixed-martial arts athletes reported experiencing a knockout, and nearly half (n = 13) reported a technical knockout.

Table 1

*Mean, Standard Deviation, and Range for Training Routines and Post Concussion Scale Scores Among MMA Athletes (*n *= 28)*

Variable	*M*	*SD*	Range
Weekly days sparring	2.6	1.1	1 - 6
Weekly minutes sparring	109.3	95	15 - 390
Knockouts	0.36	0.6	0 - 2
Technical Knockouts	1.0	1.5	0 - 6

[a] The average range of scores from a non-injured normative sample of 410 college-aged men (Iverson, Lovell, & Collins, 2003).
[b] Two individuals from the MMA group were omitted from this comparison due to exceptionally high Post-Concussion Scale scores.

Table 2 displays the mean and standard deviation for ImPACT outcome scores from athletes in the present sample as well as from the normative data for 410 university-aged males (Iverson, Lovell, & Collins, 2003).

Table 2

Dependent Variables among Athletes in this Sample, Compared to Normative Data

Variable	Athlete Group		
	MMA Athletes *(m / SD)*	Control Athletes *(m / SD)*	Normative Range[a]
Verbal Memory	84.49/10.7	88.4/9.5	83 - 94
Visual Memory	71.3/13.1	74.8/14.9	69 - 94
Reaction Time	.63/.1	.61/.1	.52 - .60
Visual Processing	35.5/6.1	38.7/6.7	32.5 - 42
Post-Concussion Scale[b]	9.04/10.3	6.3/10.5	1 - 5

Measures

In addition to reporting basic demographic information, participants were asked to provide details regarding their routine training schedules. MMA athletes were asked about their length of involvement with MMA, the number of days and time spent training in MMA per week, the number of times they have been declared knocked out (KO) or technically knocked out (TKO), and the amount of time spent in general fitness training (e.g., weightlifting, running, swimming). Non-MMA, control, athletes were asked to assess the amount of time spent in general fitness training. All athletes then completed a cognitive evaluation, using the measure detailed below.

Immediate Post-Concussion Assessment Cognitive Test (ImPACT; version 2.0.)

ImPACT (NeuroHealth System, LLC, Pittsburgh, PA) is a brief computerized neuropsychological test battery designed to assess neurocognitive functioning and concussion symptoms. The program consists of 6 individual test modules that assess attention, verbal recognition memory, visual working memory, visual processing speed, reaction time, numerical sequencing, and learning. These neurocognitive tests comprise 4 composite scores of a) verbal memory, which represents an average correct percentage for a word recognition paradigm, a symbol number match task, and a letter memory task with a concurrent interference task, b) visual memory, which consists of a composite of a memory task requiring discrimination of a series of abstract line drawings and a memory task requiring identification of a series of illuminated stimuli after an intervening task, c) reaction time, which includes an average response time on a combination of go/no-go tasks and symbol matching tasks, and d) visual processing speed, which assesses three tasks done as interference tasks on previously mentioned memory tasks (Iverson, Lovell, & Collins, 2005). Each of the test modules may contribute scores to multiple composite scores. In addition, ImPACT also contains the Post-Concussion Symptoms Scale (PCS: Lovell et al., 2006). The PCS is a subjective self-report scale designed to measure the severity of 22 commonly reported concussion symptoms (e.g., headache, dizziness, etc.) in the acute stages of concussion recovery. The ImPACT program has been used in a variety of sport-concussion research (e.g., Collins et al., 2003; Majerske et al., 2008; Van Kampen et al., 2006).

Shipley Institute of Daily Living (Shipley)

The Shipley was also presented to measure general mental abilities and to determine whether pre-existing differences in intellectual abilities may have impacted performance difference on the ImPACT measurements. The Shipley measure contains 40 questions of vocabulary knowledge and 20 abstraction questions. The total score of both subscales were combined to compute the total score. The Shipley Institute of Daily Living has previously demonstrated good internal reliability (.92) and test-retest reliability (.60-82). Construct validity has been investigated with the Wechsler intelligence scales and found to be adequate (.76 - .87).

Procedures

Athletes were recruited from local gyms offering mixed-martial-arts and alternative types of exercise such as submission wrestling, judo, and high intensity interval training (i.e. CrossFit). A combination of in-person announcements and fliers were used to inform individuals of the opportunity to participate in the research study in exchange for monetary compensation. For approximately 12 months, individuals were recruited with the opportunity to be placed in a raffle drawing for one of three $50 gift cards. Following these 12 months, procedures were revised to offer individuals a $20 participation fee. The same examiner assisted all participants throughout the completion of the study by providing web-based materials needed to complete the basic training questionnaire and Shipley cognitive measure at a convenient time of their choosing. Upon completion, participants were provided web-based materials to complete the ImPACT measure in a similar fashion. All participants and their data were treated in accordance with the Ethical Code (American Psychological Association, 2010) and with approval of the Institutional Review Board.

CHAPTER 4

RESULTS

Preliminary analysis assessed the associations among the neuropsychological variables of verbal memory, visual memory, reaction time, and visual processing speed. As shown in Table 3, each of the variables were moderately correlated with each other (range of *p*'s = < .001 - .03), with the exception of reaction time not varying systematically with verbal memory. The variable for reaction time was transformed by applying an inverse transformation to normalize the distribution. Additionally, the distribution of verbal memory was transformed by applying a squared transformation. However, these transformations had no effect on conducted analyses. As a result, relationships are reported in their untransformed units of measurement. Missing data was only observed during completion of the Shipley questionnaire. However, given the nature of the Shipley as a progressing measure of ability, it is not atypical for participants to discontinue providing responses when they become unable to formulate answers.

Table 3

Correlations among Neuropsychological Variables

Variable	Verbal Memory	Visual Memory	Reaction Time	Visual Processing
Verbal Memory	–			
Visual Memory	.45*	–		
Reaction Time	-.04	-.29*	–	
Visual Processing	.37*	.45**	-.63**	–

Note. $N = 56$, *$p < .05$, ** $p < .001$

Of primary interest was whether the performance of MMA athletes differed from non-MMA athletes on neuropsychological tasks, as it was hypothesized that MMA athletes would demonstrate significantly poorer performance on these tasks. However, t-tests for independent samples revealed no significant differences between the athlete groups on measures of verbal memory, visual memory, reaction time, or visual processing speed (all p's > .05). Additionally, a series of univariate ANCOVA's also demonstrated no significant differences between MMA and non-MMA athletes on these measures when controlling for general cognitive ability, as measured by the Shipley Institute of Daily Living (all p's > .05). Moreover, a logistic regression containing sport group as the dependent variable and the four ImPACT outcome variables as predictors failed to reliably predict performance. Although no reliable relationships were found in these analyses, any substantial relationship would have been difficult to detect. For example, power analysis indicates that a sample of this size has a 45% chance of detecting a medium effect size ($d = .5$) in performance difference between groups at the .05 confidence level. Additionally, a more modest effect size ($d = .25$) in performance difference between the two groups would have a 15% chance of being detected.

Secondary hypotheses suggested a negative relationship would exist between weekly training regimen and neuropsychological performance, as well as total duration of MMA participation and neuropsychological performance. Therefore, additional analyses were conducted to assess the relationships among the amount of time spent sparing each week, the number of days sparred each week, and the length of involvement with MMA, with neuropsychological task performance. However, as seen in Table 4 no aspects of training regimen shared a significant correlation with any of the neuropsychological tasks or a measure of cognitive ability (all p's > .05). That is, the number of days per week an athlete reported sparring, the amount of time they spent per week sparring, and the total number of days they reported being involved in MMA were not significantly related to verbal memory performance, visual memory performance, reaction time, visual processing speed, or general cognitive ability. Similar to the primary set of analyses, the likelihood of detecting a reliable relationship was low, as a sample of this size has a 26% chance of detecting correlation a modest correlation (*d* = .25) at the .05 confidence level.

Table 4

Correlations among Training Variables and Neuropsychological Outcomes

Variable	Verbal Memory	Visual Memory	Reaction Time	Visual Processing	Shipley	PCS
Days[a]	-.22	.02	-.01	.01	-.31	.07
Minutes[a]	.07	.21	-.20	.13	-.02	-.13
Total History[b]	-.14	-.21	-.07	.05	.07	.05

Note. N = 28

[a]Athletes were asked to estimate the amount of each measure of time they spend sparring each week.

[b]Athletes were asked to estimate the total amount of time they have been involved with MMA by providing as specific unit of measurement as possible (i.e., years, months, days). All responses were then converted to a continuous measure of days.

CHAPTER 5

DISCUSSION

Previous research has suggested that boxing athletes may incur more head injuries during routine sparring sessions as opposed to actual competition matches (Ravdin et al., 2003). Similarly, the amount of time mixed-martial-arts athletes' spar each week has been linked to the frequency of knockouts (Heath & Callahan 2013). Taken together, this emerging line of research suggested the possibility that the training regimens of MMA athletes, which involves elements of boxing, might place these athletes at a heightened risk for neuropsychological deficits associated with cumulative concussive injuries.

However, the neurocognitive performance of MMA athletes in this sample was not significantly different from athletes training in sports without full contact sparring. Similarly, the subjective concussion symptoms reported by MMA athletes were comparable to those reported by non-MMA athletes. Although previous research has linked MMA training regimens to the number of knockouts experienced (Heath & Callahan, 2013), no significant relationships were found in the current sample of athletes. Additionally, no reliable relationships were founds between MMA training regimens or self-reported concussive symptoms. The neuropsychological performance by both groups of athletes in the current sample was within the average level of performance in non-injured samples (Iverson, Lovell, & Collins, 2003), with the exception of evidencing marginally slower reaction time. These findings add to literature of boxing athletes suggesting typical training sessions may not have significant neuropsychological consequences (Jordan 2000; Loosemore et al., 2008).

Despite the lack of significant relationship between sport participation and neuropsychological performance in this study, conclusive findings on the effects of repeated mild traumatic brain injury remain elusive. For example, amateur boxing has been suggested as a relatively safe sport, provided basic precautionary restrictions and protective requirements are in place (Loosemore, et al., 2008; Jako, 2002). However, it has been suggested that MMA athletes may have "aggressive personalities," and disregard such restrictions in order to return to sport participation against medical advice, rather than interrupting regular training schedules (Roy & Smith, 2010, p. 23). This becomes particularly problematic when dealing with traumatic head injury, as athletes experiencing symptoms of concussion are strongly advised to refrain from physical exertion prior to the resolution of such symptoms (Aubry et al., 2002; McCrorcy et al., 2009). Athletes who return to sport participation prior to being asymptomatic place themselves at particularly high risk for subsequent traumatic brain injuries (Iverson et al., 2004). Although athletes in this sample were not found have neurological deficit, it is highly possible professional level athletes may be susceptible to early return due to financial motivation or, perhaps, personality factors (Roy & Smith, 2010).

Although training in a full contact sparring sport has been deemed relatively safe, opposing viewpoints have recently garnered significant attention. For example, the subconcussive head traumas that regularly occur as a part of soccer have been associated with abnormal brain structure as well as poor neurocognitive performance on a memory task, even when controlling for concussion history (Lipton et al., 2013). In this novel research, Lipton and colleagues highlighted the possibility of a subconcussive "threshold," a point after which cumulative subconcussive traumas become exceeded and the normal neurological healing processes become disrupted, resulting in abnormal imaging results and cognitive performance. This finding was reportedly the first to quantify subconcussive injury independent of concussion history. Although training regimens did not show a significant relationship with neuropsychological functioning in the current sample, focusing concentrated efforts into establishing detailed training patterns of MMA athletes and viewing the relationship of those specific aspects of training with neuropsychological performance may yield different findings. As evidenced by the variability of concussion symptoms reported by athletes in this sample, it is highly possible many athletes experience similar threshold effects of symptoms. However, larger samples than found in the current study would be necessary to further investigate this possibility.

In addition to recent findings of neurological changes following the accumulation of subconcussive traumas, recent research has also challenged the previously held notion that consequences following mild injuries are short-lived and transient. Zhou and colleagues (2013) conducted one of the first studies to examine longitudinal changes in brain structure following MTBI, and concluded neurological atrophy may not be exclusive to moderate and severe traumas. Participants exposed to mild traumatic injuries one-year prior to assessment were found to have not only gross loss of brain volume but in particular to the anterior cingulate, which plays a significant role in cognitive components such as selective attention, working memory, and executive functioning, all of which show notable deficit in the acute postconcussive state.

Although MMA athletes in this study showed neuropsychological task performance and postconcussion symptoms rating scores comparable to control athletes not exposed to head trauma, this finding bears important limitations that must be considered. In particular is the retrospective self-report methodology, which may have led to participants misinterpreting survey questions or providing biased/inaccurately recalled information. Even if athletes provided accurate information regarding their general training regimens, differences between "typical" levels of full contact sparring and recent levels of sparring may pose appreciable changes to outcome measures such as neurological performance or subjective symptoms. Additionally, characterizing the frequency and intensity at which athletes' spar is a complex task, as is differentiating amateurs versus professionals. Either of these factors may be related to the level of head trauma endured and subsequently effect vulnerability to injury (Jordan, 2000; Loosemore et al., 2008).

Furthermore, athletes' providing information as to the number of knockouts or technical knockouts they have endured may only prompt outcomes resulting from sanctioned competition matches, ignoring the possibility for significant concussive-like events that can occur during training (Ravdin et al., 2003). Future research is warranted to establish operational definitions of such outcomes encompassing multiple aspects of sport participation (i.e. training and competition) in order to accurately assess relationships with training regimens. Additionally, a limited self-selected sample may not accurately represent a population of athletes, as it is possible an athlete's motivation to participate in a study assessing brain function is confounded with adherence to regular safety precautions, when at least a subset of MMA athletes have been reported to favor returning to training over complying with medical advice (Roy & Smith, 2010). Future research is necessary to prospectively quantify training regimens and establish a more accurate assessment of exposure to head trauma and associated effects from this trauma on neuropsychological functioning and concussive symptoms.

A final possibility no reliable relationships were found is due to the limited size of the sample. In fact, power analyses suggest that even modest differences in neuropsychological performance differences between athlete groups, or, between aspects of training regimen and performance would have been difficult to detect given the size of the current sample. Although samples of this size are not atypical in sport concussion research these findings suggest any neuropsychological deficits MMA athletes do have may not be particularly prominent.

Previous research has suggested MMA athletes may be a particularly at-risk population given their regular training regimens expose them to various subconcussive traumas (Heath & Callahan, 2013). This is particularly problematic when considered with novel research that has shown the subconcussive traumas athletes endure may result in structural and neuropsychological consequences (Lipton et al., 2013). However, in this study of what is believed to be the first research of MMA athletes using objective neuropsychological assessment measures, athletes showed neuropsychological task performance and postconcussion symptom rating scores comparable to athletes not exposed to head traumas. Although it is possible this finding could be in part due to the measurement instrument utilized (i.e. ImPACT), this is unlikely due to the sensitivity the instrument has shown in other samples of injured and non-injured athletes. However, given the novelty of research in MMA along with the growing popularity of the sport, additional research is warranted to further assess the general neuropsychological functioning of this population similar to what has been done in other popular sports (e.g., Pellman, Lovell, Viano, & Casson, 2006; Pellman, Lovell, Viano, Casson, & Tucker, 2004).

Adding to the likelihood that use of the ImPACT measure is not the reason why group differences were not found is the finding that the training regimens of MMA athletes did not evidence reliable relationships either. Taken together, these findings suggest participation in the growing sport of MMA, by the typical non-professional, may not pose significant neuropsychological risk. However, MMA continues to rise in popularity and participation in a range of levels from recreational through professional. Additionally, the mainstream presence of the sport is novel compared to other sports that have garnered significant attention regarding concussive injury in recent years (e.g., football). Therefore, continued efforts of research specifically aimed at this population of athletes is necessary to obtain prospective information about various training regimens, the neuropsychological profiles of participants longitudinally, and to identify the state of information within the sport culture about concussive injury and brain trauma and associated management strategies. These issues become particularly important given the growing popularity of the sport, coupled with the potential factors that can influence the management of concussive injury such as incentives to return to play and availability of treatment professionals (Putukian, Aubry, McCrory, 2009). Although the current research suggests participation in MMA may not pose inherent risk factors for neuropsychological consequences, information on this growing sport is currently in a nascent stage.

APPENDIX

UNIVERSITY OF NORTH TEXAS INSTITUTIONAL REVIEW BOARD APPROVAL

UNT
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OFFICE OF THE VICE PRESIDENT FOR RESEARCH AND ECONOMIC DEVELOPMENT
Research Services

June 22, 2011

Christopher Heath
Department of Psychology
University of North Texas

Institutional Review Board for the Protection of Human Subjects in Research (IRB)
RE: Human Subject Application #09234

Dear Mr. Heath:

The UNT IRB has received your request to modify your study titled "Assessment of Cognitive Performance in Mixed Martial Arts Athletes." As required by federal law and regulations governing the use of human subjects in research projects, the UNT IRB has examined the request to add questionnaire and brief interview to this study. The modifications to this study are hereby approved for the use of human subjects. **Federal Policy 45 CFR 46.109(e) stipulates that IRB approval is for one year only, September 3, 2010 to September 2, 2011.**

Enclosed is the consent document with stamped IRB approval. Please copy and use this form only for your study subjects.

Please contact Shelia Bourns, Research Compliance Analyst, at (940) 565-3940, or Boyd Herndon, Director of Research Compliance, at (940) 565-3941, if you wish to make changes or need additional information.

Sincerely,

Patricia L. Kaminski, Ph.D.
Associate Professor
Chair
Institutional Review Board

PK/sb

1155 Union Circle #305250 | Denton, Texas 76203-5017 | TEL 940.565.3940 | FAX 940.565.4277
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