



Neuropsychological Consequences of Boxing and Recommendations to Improve Safety: A National Academy of Neuropsychology Education Paper[†]

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Abstract

Boxing has held appeal for many athletes and audiences for centuries, and injuries have been part of boxing since its inception. Although permanent and irreversible neurologic dysfunction does not occur in the majority of participants, an association has been reported between the number of bouts fought and the development of neurologic, psychiatric, or histopathological signs and symptoms of encephalopathy in boxers. The purpose of this paper is to (i) provide clinical neuropsychologists, other health-care professionals, and the general public with information about the potential neuropsychological consequences of boxing, and (ii) provide recommendations to improve safety standards for those who participate in the sport.

Keywords: Boxing; Brain damage; Neuropsychological evaluation

Neurological Injury in Boxing: An Overview

Individual combat competitions have occurred throughout recorded history. Despite, or because of its violent nature, boxing has held appeal for many athletes and audiences for centuries, and it has long been part of the international Olympic Games. Injuries have been part of boxing since its inception. As the sport has evolved, however, rule and equipment changes have improved safety aspects of the boxer. Consistent with most sports, boxing includes both amateur and professional levels. Differences in objectives, rules, and safety equipment convey different risks for amateur and professional boxers (see

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www.ozboxing.org/health/difference.htm). Because of these differences, the scientific literature reviewed in this paper is separated for amateur and professional boxing when appropriate.

Epidemiologic studies that have analyzed the frequency of neurologic injuries in amateur and professional boxing suggest that permanent and irreversible neurologic dysfunction does not occur in the majority of participants (see Heilbronner & Ravdin, 2004 for a review). The frequency of acute, transient neurologic injuries in professional boxers is estimated to be 0.8 brain injuries per 10 rounds and 2.9 brain injuries per 10 boxers. Rarely does the brain injury yield persistent neurologic dysfunction as assessed by routine neurologic examination. It is important to note, however, that neuropsychological measures were not included in most of these studies.

Deaths from boxing tend to be widely publicized; however, the actual number of deaths is quite low. One estimate indicates a fatality rate of 0.13 deaths per 1,000 participants per year (American Medical Association, 1983; cf. Cantu, 1995). This fatality rate is lower than or similar to the rates of other high-risk sports, such as college football, motorcycle racing, scuba diving, mountaineering, hang gliding, sky diving, and horse racing. Fatalities occur less often among amateur than professional boxers, averaging at about three deaths per year compared with 9–10 deaths per year from professional boxing.

Multiple Subconcussive Head Blows

Despite the dramatic effects of the knockout (KO) punch, the cumulative effects of multiple subconcussive head blows appear to be the primary cause of neurologic injury in boxers, especially for a subset of professional boxers with extensive fight histories (Jordan et al., 1992). Several studies found associations between the number of bouts fought and the development of neurologic, psychiatric, or histopathological signs and symptoms of encephalopathy (Casson, Siegel, Sham, Campbell, Tarlau, & DiDomenico, 1984; Drew, Templer, Schuyler, Newell, & Cannon, 1986; Jordan, Relkin, Ravdin, Jacobs, Bennett, & Gandy, 1997; Ross, Cole, Thompson, & Kim, 1983). The neuropathological damage sustained by boxers includes cerebellar abnormalities, cerebral scarring and atrophy, degeneration of specific nuclear groups (i.e., the substantia nigra, locus ceruleus, and nucleus basalis of Meynert), neurofibrillary tangles, and damage to the cavum septum pellucidum (Corsellis, Bruton, & Freeman-Browne, 1973; Stiller & Weinberger, 1985).

Second Impact Syndrome (SIS) is an extremely rare condition that occurs when an athlete sustains a brain injury and subsequently receives a second brain injury before the effects of the first injury have fully resolved (Saunders & Harbaugh, 1984). The second affect may initially appear minor, but can quickly evolve into respiratory failure, and death may occur (Cantu, 1992). There have been case reports of boxers who have sustained SIS (e.g., Cantu & Voy, 1995). These catastrophic events have been attributed to cerebrovascular dysregulation, vascular engorgement, and herniation of brain tissue into the foramen magnum. Similar to that observed in other sports, younger boxers are at greater risk for the SIS. Animal research suggests that there is a “critical period” during maturation when the developing brain has greater vulnerability due to slower biochemical and physiological recovery when compared with the adult brain (Prins & Hovda, 2003). Specifically, hypotension secondary to brain injury in the developmentally immature animals appears to explain the greater mortality among the younger animals. SIS has been questioned as a diagnostic entity. An alternate explanation attributes deaths in these situations to the likely post-traumatic complication of diffuse cerebral swelling (McCrory, 2001), which is a very rare and catastrophic consequence of a *single* seemingly mild brain injury.

It has been predicted that the incidence of chronic neurological problems related to the sport of boxing will decline over time (Clausen, McCrory, & Anderson, 2005). Such a decline in serious injuries may occur due to decreased duration of boxing careers, reduced mean number of career bouts, improved safeguards, increased medical supervision, better equipment, and more forced layoffs and retirements of boxers. In addition, increased awareness on the part of ringside physicians, athletic trainers, and boxers will likely contribute to a decreased incidence of severe neurological problems related to boxing due to earlier identification and management of initial neurological and neuropsychological signs and symptoms.

The Risk of Boxing-Induced Neurologic Complications

Neurological trauma from boxing has three primary manifestations: (i) acute neurologic injuries; (ii) persistent groggy states and the post-concussion syndrome; and (iii) chronic traumatic encephalopathy (CTE), commonly referred to as the “punch-drunk syndrome” or “dementia pugilistica.”

Acute Neurologic Injuries

KO is the most obvious acute neurologic injury in boxing. The loss of consciousness produced by the KO blow is abrupt in onset, and typically quite brief in duration. The KO usually results from a direct blow to the face resulting in an acceleration or

torque rotational force which is transmitted to the brain, affecting the cerebellum and brain stem, thereby causing imbalance and unsteadiness making the boxer unable to remain standing. It is important to note that relying on “knockouts” as the measure of neurologic injury may underestimate the true rate of concussive head blows in boxing, because most studies define the classic KO as the fighter’s inability to stand for 10 s, which may or may not involve a true loss of consciousness. A technical knockout (TKO) occurs when a referee stops the fight because the fighter is unable to continue for various reasons. Given the relative infrequency of the classic KO (estimated at about six per 100 bouts), these types of blows to the head do not appear to be the primary reason for the brain damage seen in some boxers (Morrison, 1986).

Post-concussion Syndrome

Some boxers experience persistent residual cognitive and physical symptoms, such as headaches, dizziness, balance difficulty, and memory problems for many days or weeks after a fight. This is often referred to as a “groggy state,” or more commonly the post-concussion syndrome. Most often, the boxer appears to recover symptomatically, returns to his previous level of cognitive and physical functioning, and fights again. Over time, however, some boxers (usually those with the most extensive fight histories) experience longer durations of symptoms. When post-concussion symptoms become more common, and last longer, that boxer is at risk of long-term problems, including the development of CTE. However, more research is needed to completely examine the role of persistent post-concussion symptoms in the possible transition into CTE.

Chronic Traumatic Encephalopathy

CTE, also referred to as “dementia pugilistica” or the “punch drunk-state” consists of a spectrum of neurologic disorders arising from chronic exposure to cerebral trauma and is characterized by disturbances in speech, gait, cognition, and behavioral or personality changes (Jordan, 1993). Motor impairments can include dysarthria, cerebellar ataxia, parkinsonism, spasticity, and hyperreflexia (Jordan, 1987). The specific neuropsychiatric manifestations include personality changes, rage reactions, impulsivity, and childishness (Johnson, 1969; Mendez, 1995). Neuropsychological investigations have documented impairments in memory, speed of information processing, complex attention, and executive functioning (Casson et al., 1984; Drew et al., 1986; Johnson, 1969; Jordan, Matser, Zimmerman, & Zazula, 1996; Kaste, Kuurne, Vilkki, Katevuo, Sainio, & Meurala, 1982; Ross, Casson, Siegel, & Cole, 1987). CTE is positively correlated with the frequency and degree of boxing-related injuries as measured by number of bouts, sparring exposure, and abnormalities on neuroimaging (Casson et al., 1984; Jordan et al., 1996; Ross et al., 1987).

The literature on CTE generally consists of studies of professional boxers. Amateur boxing affords less exposure to brain trauma because of the standard use of head gear, shorter, and fewer rounds compared with professional bouts, and reduced force based upon acceleration and mass. Chronic neurologic dysfunction in amateur boxers can involve isolated signs and symptoms that are relatively mild in degree (Thomassen, Juul-Jensen, de Fine Olivarius, Braemer, & Christensen, 1979). Stewart and colleagues (1994) reported a trend between neuropsychological test scores and past, but not recent, number of fights, and rounds fought. They suggested that there might be a latency period which is consistent with the theory that prior brain injury increases vulnerability to future neuropathology (Cantu, 1992; Carlsson, Svardsudd, & Welin, 1987), but they also acknowledged that their results may be confounded by increased safety measures instituted in 1986. Generally speaking, the majority of studies suggest that amateur boxing does *not* lead to the extent and degree of deficits found in professional boxers with evidence of CTE (Butler, Forsythe, Beverly, & Adams, 1993; Casson et al., 1984; Murelius & Haglund, 1991; Stewart et al., 1994).

High exposure to boxing in and of itself does not appear to be sufficient to cause CTE. Calne, Eisen, McGeer, and Spencer (1986) posited that the late life dementia experienced by some retired professional boxers results from the combined damage of boxing-related injury and age-related neuronal loss. That is, a critical number or percentage of neurons must be damaged or destroyed by a combination of trauma, age-related atrophy, and/or other causes in order to develop dementia later in life. Based on the theory of cognitive and cerebral reserve (Stern, 2002), boxers who end their boxing careers and have experienced some neuronal loss may not exhibit signs of CTE as long as a critical number or percentage of functioning neurons remain. With the combination of neuronal reduction associated with multiple subconcussive head blows, advancing age, and perhaps some other health conditions and disease processes (e.g., hypertension, heart disease, diabetes, chronic alcohol abuse), former boxers may develop clinical signs of dementia at an earlier age than non-boxers. Although epidemiological studies are needed to make such a determination, this cognitive reserve model may help to explain why, in many cases, CTE emerges after the end of a boxing career (Jordan, 1993).

Genetic factors, specifically the apolipoprotein E (APOE) genotype, may place some boxers at increased risk for the development of CTE. APOE-e4 is a genetic susceptibility factor for Alzheimer’s disease (Roses et al., 1996) and other late life

cognitive disorders. Jordan and colleagues (1997) found that all of the boxers in their study who sustained severe chronic TBI and cognitive impairment possessed at least one copy of the APOE-e4 allele. Research with mixed TBI populations (i.e., accidental head trauma), however, has found non-significant associations between the presence of the APOE-e4 allele and poor neuropsychological or functional outcome following mild-moderate TBI (Chamelian, Reis, & Feinstein, 2004; Han et al., 2007; Liberman, Stewart, Wesnes, & Troncoso, 2002; Millar, Nicoll, Thornhill, Murray, & Teasdale, 2003). In addition, other factors, such as age and the cumulative effects of mild TBIs, may interact with APOE-e4 allele status to affect neuropsychological outcome (Kutner, Erlanger, Tsai, Jordan, & Relkin, 2000; Teasdale, Murray, & Nicoll, 2005). Although some evidence suggests that individuals with APOE-e4 and a positive history of head trauma are at increased risk for early-onset dementia when compared with APOE-e4 carriers with no prior head trauma (e.g., Mayeux et al., 1995), Jellinger (2004) concluded that “the relationship between dementia after head/brain trauma and apolipoprotein E status is still ambiguous” (p. 719).

Factors such as a boxer’s style and skills may also be important variables in the development of chronic neurological problems, yet these variables are very difficult to quantify and study systematically. Comorbid conditions (e.g., learning disorders, psychiatric problems, substance abuse) can also complicate the initial diagnosis of CTE. Thus, the relationships between TBI, other potential risk factors such as APOE-e4 allele status, comorbid conditions, and neuropsychological status in later life is extremely complex and, in the context of a particular sport, such as boxing, much more empirical evidence is needed before firm conclusions can be drawn.

Neuropsychological Studies of Boxers

Only a few published studies have examined the neuropsychological functioning of professional boxers. In one study, neurocognitive tests measuring planning, attention, and concentration, and memory were the most sensitive measures of brain dysfunction in professional boxers (McLatchie et al., 1987). In another study of professional boxers, neurocognitive test scores one month following their bouts were better than their baseline scores (Ravdin, Barr, Jordan, Lathan, & Relkin, 2003). The authors suggested that the baseline scores may have been confounded by pre-bout factors such as sparring, rapid weight loss, and pre-bout anxiety, and therefore may not have represented the boxers’ true baseline abilities. Although alternate test forms were used, practice effects may have also contributed to improved test performance. These investigators also found that boxers with the most professional experience (i.e., more than 12 bouts) had some evidence of poor neurocognitive performance during the presumed recovery period. Other researchers reported that both the number of bouts and number of losses plus draws correlated with cognitive deficits in professional boxers (Drew et al., 1986; Stewart et al., 1994). In addition, increased sparring exposure was related to worse neuropsychological performance, primarily on tests involving attention, concentration, and memory (Jordan et al., 1996). Thus, degree of sparring exposure, rather than the number of actual competitions, appears to be associated with worse cognitive functioning in some boxers.

Studies of the neuropsychological affect of amateur boxing revealed few, if any, neurocognitive deficits (Moriarity et al., 2004; Porter, 2003; Porter & Fricker, 1996; Stewart et al., 1994; Timm, Wallach, Stone, & Ryan, 1993). Moriarity and other researchers (2004) examined amateur boxers participating in multiple bouts during a 7-day tournament and found that, with the exception of those whose contests were stopped by the referee, there was no evidence of cognitive dysfunction in the immediate post-bout period. Porter (2003) followed 20 amateur boxers over a 9-year period and found no evidence of decreased neurocognitive test performance. In fact, the boxers evidenced significantly better performance over time than age-matched controls. Porter and Fricker (1995) found no evidence of neuropsychological impairment in amateur boxers compared with controls, and there was no association between neuropsychological performance and boxing exposure. Timm and colleagues (1993) examined boxer safety and concluded that serious injuries occurred very rarely and that amateur boxing is generally a safe sport.

When neurocognitive deficits have been evident in amateur boxers, they occurred primarily on tasks measuring attention, concentration, memory, and motor speed (Brooks, Kupshik, Wilson, Galbraith, & Ward, 1987). Those amateur boxers with the most ring experience showed greater adverse effects, but the magnitude of their deficits was considered mild, relative to normative control groups. Compared with other examination procedures (e.g., neurologic exam, computed tomography scan, electroencephalogram), neuropsychological tests are the most sensitive method for detecting neurological dysfunction in active amateur boxers (Ross et al., 1983). This line of research has led some investigators to conclude that carefully controlled durations of amateur boxing may indeed be neuropsychologically safe (Butler et al., 1993). One limiting factor associated with boxing studies, however, is participant self-selection; that is, boxers who decline to participate in such research may differ in important ways from those who agree to participate.

Stewart and colleagues (1994) found statistical trends between the total number of bouts fought prior to a baseline exam and changes in memory, visual-constructional ability, and perceptual-motor ability over time. No significant associations were found between the number of bouts that occurred after the baseline assessment and neurocognitive abilities, or between number of bouts or sparring exposure and other outcome measures such as brain stem auditory-evoked potentials and

electroencephalography. This study provided evidence that an increased number of bouts in the past might be associated with diminished performance in selected cognitive domains, but none of the observed changes were considered clinically significant. The evidence to date appears to indicate that, in general, amateur boxers may escape chronic neurological problems provided that their total ring exposure is limited both in frequency and duration.

Recommended Concussion Assessment and Management Protocol

Neuropsychological measures are sensitive to cerebral compromise, and neuropsychological evaluations generally consider a broad range of neurological, emotional, and psychosocial factors that can affect post-concussion recovery. For these reasons, neuropsychological evaluations may prove useful in the context of establishing cognitive baselines, objectively measuring post-injury deficits, as well as making decisions regarding return to the ring and retirement from the sport. Boxers may be evaluated at different times, in different settings, and with different methodologies; to date, no single protocol has demonstrated an empirically validated superiority.

It is important to note that, at present, there is no generally accepted definition or grading for the diagnosis of a concussion. Two frequently used systems for grading sports-related concussions are those proposed and revised by Cantu (1986, 2001) and the American Academy of Neurology (1997). These two systems specify loss of consciousness, confusion, and post-traumatic amnesia as important criteria for determining the presence and severity of concussion. The purpose of these gradations is to standardize the classification scheme of concussion severity, with the goal of potentially influencing clinical management (e.g., return to competition or practice) or developing interventions that are specific to various gradations of injury severity.

Baseline Neuropsychological Evaluation

Establishing a neuropsychological baseline of boxers can contribute clinically meaningful data in protocols designed to protect athletes. Through comparison of baseline scores to post-bout scores, clinicians can use quantitative neurocognitive data when making return-to-ring recommendations. The use of baseline testing also allows for the evaluation of boxers over time and assists in tracking them throughout their careers and post-boxing lives. Pre-injury individual differences in performance between boxers in attention, memory, and processing speed are common and it is important to identify these individual differences at baseline rather than misattributing weaknesses or deficits to boxing-related injury. Pre-injury learning disabilities, attention-deficit/hyperactivity disorder, limited education, cultural factors, or test-taking anxiety can affect test scores. Test results may also be affected by previous concussions sustained either inside or outside the ring. For these reasons, baseline neuropsychological evaluations performed at or near the beginning of boxers' careers may potentially add clinically meaningful data for determining intraindividual changes over time.

Ringside Evaluation

The ringside physician is usually the first professional to evaluate the boxer following a KO or TKO, performing a gross neurologic examination and possibly a cursory mental status exam. These examinations are important for identifying potentially life-threatening or seriously disabling conditions (e.g., cerebral hemorrhage or edema), but they are not sufficiently sensitive for detecting and quantifying emerging cognitive deficits which may develop following the bout.

An appropriate ringside neurocognitive evaluation should involve an assessment of the boxer's orientation to place, bout, and details of the bout. The boxer's recall of events preceding the KO/TKO should be evaluated, as well as the ability to learn and retain new information. Through these methods, retrograde and post-traumatic amnesia may be detected. Brief tests of attention and memory and observations for emerging post-concussive physical symptoms, such as headache, nausea, imbalance, or confusion, should also be performed. The Standardized Assessment of Concussion (McCrea et al., 1998) is one example of a brief, yet empirically based assessment tool that may be useful in the ringside assessment of a boxer's mental status. It may be used in conjunction with a brief neurologic examination or neurologic checklist such as the Sideline Concussion Checklist (Kutner & Barth, 1998).

Post-injury Neuropsychological Evaluation

Boxers should undergo a thorough neuropsychological evaluation following a KO or TKO. Some clinicians believe that such evaluations should be done within 24–48 hr following a bout; however, others advocate waiting until the boxer is symptom-free on a standard neurologic exam and has normal neuroimaging (which is often required by state boxing commissions under these circumstances). Even when a boxer appears to be symptom-free and denies subjective problems, a

neuropsychological evaluation may detect neurocognitive dysfunction. Neuropsychological evaluations following KO or TKO is especially important because some athletes are prone to under-report their symptoms in hopes of a speedy return to competition (Echemendia, 2006). If the boxer displays *any* cognitive deficits on testing, a follow-up neuropsychological evaluation is indicated prior to returning to sparring or competition. Animal and in vitro neuroscience studies have demonstrated metabolic changes in the brain that persist for several days following injury (e.g., Hovda, Prins, Becker, Lee, Bergneider, & Martin, 1998). Repeat testing in 5–7 days is commonly used in college and professional sports concussion protocols (Echemendia, 2006; McCrea et al., 1998).

Return-to-Ring Guidelines

Multiple approaches to assist with return-to-play (RTP) decisions have been proposed for other sports (Echemendia & Cantu, 2003) and various states have laws about mandatory times between bouts and length of no-boxing periods following KOs. Interestingly, boxing is currently the only sport that has these clinical practices mandated by law. RTP decisions typically take into account many variables that interact in complex ways – some direct (e.g., medical factors) and some indirect (e.g., political issues). Echemendia and Cantu (2003) proposed a dynamic model that takes into consideration the following factors: concussion, medical, neuropsychological, athlete, and other extraneous factors. The model is based on the premise that no RTP decision is ever risk-free. RTP decisions should be made on an individual basis and, at a minimum, take into consideration the athlete's concussion history, performance on ringside cognitive screening, and more comprehensive neuropsychological examination, and report of post-concussive symptoms.

It is recommended that before returning to the ring, the boxer (i) must be free of all post-concussive symptoms at rest; (ii) have a normal neurological exam; (iii) have neuropsychological test scores that are comparable with baseline scores (if baseline scores were obtained); and (iv) must not have neuroimaging findings of structural lesion(s). Progressive exertional challenges (e.g., light aerobic exercise leading to more vigorous aerobic challenges, followed by strength work such as push-ups) should be included to push the boxer to near maximal heart rate (cf. Vienna Guidelines). If the boxer remains symptom-free throughout the exertional challenges, then clearance to return to sparring can be given with increased confidence.

There are a number of persons who should be involved in the decision to return a boxer to sparring or competition following a KO or TKO. The boxer, trainer, family members, physician, and neuropsychologist all may provide input into this decision. Nevertheless, the state boxing commission, utilizing multiple sources of information, ultimately makes the final determination about if and when a boxer may return to competition in that state.

Retirement Decisions

At present, it is unknown exactly how many fights, punches, KOs/TKOs, and years of boxing a boxer can withstand before developing signs and symptoms portending the development of CTE. Yet, evidence suggests that the longer one engages in a boxing career, the greater the risk for incurring permanent brain damage from concussive or multiple subconcussive head blows. Exactly when a boxer “should” retire is a difficult question to answer, especially in the context of personal liberties and freedom of choice to make informed decisions about one's future. Disagreement arises about the number of concussions that might be experienced before advising an athlete to stop boxing: this disagreement is also encountered in other contact sports. Under rare circumstances, some individuals can sustain a single brain injury that leaves them with permanent post-concussive symptoms and neurocognitive deficits that prohibit a return to contact sports. Others may sustain multiple low-grade concussions without any obvious permanent sequelae. Although there is no universal consensus on when a boxer's career should end, there is general agreement that an athlete who continues to experience post-concussive symptoms at rest or provoked by exertional exercise should not return to a contact sport (Echemendia & Cantu, 2003).

According to Echemendia and Cantu (2003), there are two main clinical changes that should raise concern about when the multiply concussed athlete should cease engaging in contact sports. The first regards the change in *duration* of post-concussive symptoms (PCS). Usually, PCS clear within a few days or weeks. For some athletes with a history of multiple concussions, however, the duration of PCS tends to last longer. This progressively increasing period of symptom duration should be a warning sign that return to competition might not be advisable. The second change that should raise concern is the nature of the *force* required to produce a concussion and lingering PCS. Blows that produce concussion usually strike the head; however, there is anecdotal evidence that some athletes with a history of multiple injuries become more susceptible to a concussion from blows to other parts of the body, especially the chest and posterior thorax. This change in susceptibility to concussion is especially relevant in boxing where punches are delivered to both the body and head. When hits to the body produce neurological dysfunction, it is strongly recommended that the boxer consider retirement. Mandatory referral for

neuropsychological assessment should occur when a boxer starts to show such evidence of (i) longer duration of PCS and/or (ii) increased susceptibility to concussions.

Ethical Considerations

The American Medical Association, Australian Medical Association, and World Medical Association have provided position statements opposing boxing and recommending that boxing be banned (American Medical Association, 1999; Australian Medical Association, 2007; World Medical Association, 2003). These associations have offered recommendations for improving safety aspects of the boxer until such time as the sport is banned. Such positions reflect the ethical principle of beneficence; that is, opposing and banning boxing is intended to advance and protect the health of individuals who may otherwise be injured from boxing (Leclerc & Herrera, 1999).

However, the positive aspects of boxing must also be considered, including (i) the health benefits that result from the training involved with boxing, (ii) cultural traditions, and (iii) economic opportunities for boxers. Adult boxers have the right to make informed decisions of whether to participate (Warburton, 1998).

To make an informed decision, boxers and other decision-makers must possess and understand the potential risks and benefits, based on the scientific information available at the time. It is the responsibility of boxers to seek such information; however, it is also the responsibility of trainers, healthcare professionals, boxing commissions, and others to provide the information and explain it in a manner that can be readily understood by the boxers. Healthcare-related professional organizations are able to assist boxers and others by objectively reviewing and summarizing the information, so that interested and involved parties can make informed decisions.

Conclusions and Recommendations

A great deal of research has occurred over the past 10 years, but there is much that is still not understood about boxing-related brain injury. What is known is that boxing mortality rates are comparable with other high-risk sports, and long-term neurologic compromise in boxers is found in only a very small percentage of those involved in the sport, more often in professional fighters with extensive careers. Although empirical data to answer many questions is still lacking, the available evidence provides some useful information to design methods (e.g., reduced number of rounds and bouts, rule changes) and equipment (e.g., head gear) to improve professional boxing safety.

It is recommended that researchers examine high-risk variables such as the number of bouts and sparring matches, previous concussions, age of the fighter, genetic profile, frequency of head blows, and velocity of punches, and identify whether there is a critical number of fights, KOs, or punches that result in cerebral and neurocognitive compromise. Because neuropsychological testing has been shown to be sensitive to sports-related concussions in cases where the results of other medical exams (e.g., neuroimaging and neurologic exam) are normal, it is recommended that baseline and serial neuropsychological assessments be regularly employed to monitor changes in neurocognitive status throughout a boxer's career. Systematic monitoring of the neurocognitive status of boxers would allow for appropriate interventions and decisions about participation in order to promote neurological health. Such monitoring would also help to identify early mild neurocognitive compromise that could possibly progress to the more significant symptoms associated with CTE.

Ideally, medical and athletic organizations and state boxing commissions can collaborate on a national consensus directed toward minimum medical requirements that include neuropsychological status before a boxer can get licensed and/or return to the ring. Such a national consensus is particularly important because, under current regulations, a boxer who may not be able to get licensed in one state can still get licensed in another jurisdiction with less stringent medical requirements. Through its educational outreach programs, the National Academy of Neuropsychology welcomes collaboration with other healthcare organizations and state boxing commissions both in the development of guidelines that promote boxer safety and in the pursuit of increased understanding of the neuropsychological consequences of boxing.

Conflict of Interest

Some authors (J.T.B., R.J.E., G.L.I., M.R.L.) have been reimbursed by the government, professional scientific bodies, sporting organizations, and commercial organizations for discussing or presenting research relating to MTBI and sport-related concussion at meetings, scientific conferences, and symposiums. Some authors (D.K.B., R.J.E., M.R.L.) are reimbursed by sporting organizations for clinical and academic consulting relating to sport concussion. Some authors (D.K.B., D.K.B., R.J.E., G.L.I., M.R.L.) have received external funding for research relating to sport concussion. G.L.I. has received research

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