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Ethical Implications of Neuroimaging in Sports Concussion

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The Centers for Disease Control and Prevention estimates that 1.6 to 3.8 million traumatic brain injuries that occur each year are related to sports injuries. New research has broadened the understanding of the acute and chronic pathophysiology of concussion associated with brain injury, and recent advances in diagnostic capabilities with neuroimaging are leading to new ethical questions around sport and care of the head-injured athlete. In this review, we synthesize the current literature on neuroimaging for assessing concussed athletes and explore ethical issues in the context of return to play, short- and long-term neurologic health effects following concussion and resource allocation that are emerging with new implications as neurotechnology becomes an increasingly powerful tool on the playing field of health. **Keywords:** *concussion*, *neuroethics*, *neuroimaging*, *sports*

THE Centers for Disease Control and Prevention estimates that 1.6 to 3.8 million traumatic brain injuries (TBIs) that occur each year are related to sports injuries.[1] Concussion, a minimal to mild form of traumatic brain injury (mTBI), characterizes the majority of these occurrences. It is defined as a complex pathophysiological process of the brain induced by traumatic biomechanical forces.[2,3] Classic animal studies have demonstrated cerebral vulnerability during the acute postconcussive state.[4,5] In humans, modern neuroimaging techniques such as magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) are enabling better visualization of the microstructural and functional damage occurring post concussion, and are providing more accurate diagnosis of injury severity and timing of axonal recovery. In 2010, research on the effects of repeated concussion led to revision of concussion policies by major US sports leagues and state legislation. This fueled media interest and propelled the American Academy of Neurology to develop a revised position statement on concussion.[6]

Alongside new diagnostic capabilities and the attention they have garnered are uncharted challenges at the intersection of neurologic health, sport, and decision making. In this review, we synthesize the current literature on neuroimaging for assessing concussed athletes. Through the lens of neuroethics that bridges advances in neuroscience and biomedical ethics, we explore specific dilemmas in the context of return to play decision making, short- and long-term health effects to the athlete following concussion, and resource allocation. Our working premise is that as neurotechnology is becoming an increasingly powerful tool in the field of health care, it will become an increasing force on the playing fields of sport. In this perspective, we discuss predicted ethical challenges and the critical thinking and fresh answers they will require. Recognizing that our analysis is nonexhaustive, we hope to encourage future dialogue regarding management and ethical implications of neuroimaging in sport.

NEUROIMAGING OF mTBI AND CONCUSSION

Recent reviews have explored advantages and disadvantages of neuroimaging techniques in sport related concussion and mTBI.[7–9] Here, we will only briefly discuss DTI and functional MRI, examples of techniques that hold the most promise in a clinical setting. The contributions of other techniques such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT) are clearly substantial, but they do not have the immediate implications for sports concussion as the less invasive MRI.

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DTI

Diffusion tensor imaging utilizes the diffusion of water in the brain for imaging purposes. It provides measures of water movement in 6 or more directions (a matrix or tensor). Anisotropy, in this context, is the linear diffusion of water, and a fractional anisotropy (FA) index of 1 suggests maximal diffusion in one direction as seen in tight white matter fiber tracts of healthy individuals. Isotropic diffusion is seen in subcortical regions when there is micro architectural damage as with concussion. In theory, with an increase in random diffusion, FA will approach 0 in disrupted white matter fiber tracts.

In recent studies using DTI, Arfanakis et al[10] showed abnormalities in the internal capsule and the corpus callosum of 5 subjects 24 hours post-mTBI when compared with imaging of 10 control subjects. Rutgers et al[11] reported that patients who experienced mTBI exhibited white matter changes several months after injury. Subsequent studies also have been able to relate abnormal FA with neuropsychological and cognitive impairments. Niogi et al,[12] for example, demonstrated that the amount of white matter injury is correlated with mean reaction time on simple cognitive tasks. In a study conducted by Lipton et al,[13] abnormalities of the internal capsule in patients with a history of mTBI correlated with impairment in neuropsychological testing. This included tasks to evaluate language, memory, attention, and executive functions. These authors extended their research by demonstrating a relationship between the area of white matter injury–dorsolateral prefrontal cortex–and impaired executive function using DTI.[14] They demonstrated this relationship in a very mild TBI group in which only 2 of the 20 patients had lost consciousness following the trauma. Further to this, Wilde et al[15] found that changes in FA correlated with postconcussive symptom severity in adolescents with mTBI when correlating with the Rivermead Concussion Scale.

Taken together, these studies and others[16,17] suggest that mild TBI is associated with significant widespread microstructural changes in white matter during the early postinjury state as depicted on DTI. This is a potentially powerful modality, therefore, for unveiling subclinical axonal injury in sports concussion.

Functional MRI

Functional MRI (fMRI) has been more widely used than DTI to study mTBI and concussion. Functional MRI relies on blood oxygenation-level–dependent (BOLD) signals to reveal regional shifts in oxyhemoglobin and deoxyhemoglobin in the context of task-specific activity. Using a working memory task paradigm, Chen et al[18] were the first to show abnormal BOLD activation patterns in the dorsolateral prefrontal cortex in symptomatic concussed athletes and, later, normalization of these activation patterns with improvement in post concussive symptoms.[19] Other studies by McAllister et al[20,21] showed deficits in working memory and atypical frontal and parietal patterns of activation during attention tasks. In a prospective fMRI study, Jantzen and colleagues[22] examined college football players prior to and following concussion. Baseline preseason neuropsychological testing was conducted along with fMRI, and results of 8 injured athletes were compared with their test results during the regular season 1 week postconcussion. Although BOLD signal differences were observed in the concussed athletes compared with baseline, no reliable changes were found on neuropsychological testing.[22]

Taken together, DTI and fMRI have shown promising results in the laboratory setting. In the practical setting, these technologies are not without limitation as all the studies described rely on statistical analysis of group data. Translating the functional capabilities to clinical use technology hinges on technological advances that further enable computation of complex activation signals for individuals and an understanding of the meaningfulness of normative group data for individuals. Furthermore, fMRI signal cannot clearly distinguish neural network processing from neuromodulation or even areas of excitation and inhibition.[23] Diffusion tensor imaging shares limitations with fMRI in distinguishing abnormal signals, with conflicting results as to whether decreased FA[10,12,14] or increased FA[15] represents lack of structural white matter integrity. Caution must be taken when interpreting these experimental protocols, as there is still a lack of understanding regarding the connectivity of normal neural networks, let alone in the pathological state.

ETHICS ON THE FIELD: NEUROIMAGING AND CONCUSSION

Ever-improving diagnostic capabilities, especially ones that may be applied in near real-time, have brought both benefits and challenges grounded in biomedical ethics to sport concussion. As they involve brain specifically, we may refer to them as neuroethical challenges, embodying notions of "... how we want to deal with the social issues of disease, normality, mortality, lifestyle, and the philosophy of living informed by our understanding of underlying brain mechanisms."[24(p29)] In the broad context, neuroethics deals with ethical, legal and social implications of neuroscience research, extending the fundamental principles of biomedical ethics of respect for autonomy, beneficence, nonmaleficence, and justice.[25,26] It is our view that for the neurosciences to be applied for maximum public health good, it is critical to identify and address the ethical challenges arising from neurotechnology at their earliest stages. Guidance offered as a result must be practical, flexible, and maximally responsive to the dynamic evolution of both the science and technology. We examine the case that neuroimaging will enter the sports arena in the 3 contexts in which we predict they will become most compelling: (1) return to play following concussion, (2) short and long-term health effects of concussion, and (3) resource allocation.

Return to play

One of the most critical questions affecting athletes and their coaches is the safe time to return to play (RTP) after a concussion. In 2009, the third International Meeting on Concussion in Sport delivered the third iteration of the most widely accepted set of guidelines for RTP.[3] The common acute signs and symptoms of concussion include, but are not limited to, loss of consciousness, headache, confusion, amnesia, disorientation, incoordination, and balance impairment. In professional sports, the diagnosis is typically made by team doctor, team trainer, neuropsychologist, or other affiliate of the team. To date, best practice discourages athletes from returning to play on the day of injury and introduces them into a graduated RTP protocol.

Guidelines regarding RTP are established to avoid further harm to the athlete, despite limitations on autonomy and decision making. This paternalism protects athletes and stands in sharp contrast to the strong incentive to return players to the game as early as possible given the significant impact they can have on its outcome.[27] Ted Johnson, for example, a former New England Patriots linebacker, was cleared to return to practice 4 days after suffering a concussion in game, despite being symptomatic; details of the repeated concussions he suffered and inappropriate RTP surfaced years later.[27,28] Johnson admitted partial responsibility for early RTP, not wanting to further tarnish his reputation with the team and coaching officials.[24]

The case above exemplifies the explicit and implicit coercion potentially imposed on athletes. Although explicit coercion might involve direct pressure by coaches, implicit coercion refers to the internal pressure experienced by athletes to RTP inappropriately early, to appease the teammates, affiliates of the team, and team fans. The extent of implicit coercion on each athlete is variable, but athletes are unique in a patient population as they often minimize symptoms to continue participating in sport.[29,30] One report suggests that athletes may not perform to their highest potential during preseason baseline neuropsychological testing to create a low threshold for comparison if re-evaluated for RTP postconcussion.[31] Anecdotal evidence also suggests that athletes practice sideline neuropsychological testing–for example, reciting months of the year backwards–to improve performance following concussion.[32] Both strategies are potentially dangerous to the athlete, setting an erroneous neurologic and cognitive threshold for assessment. With advances in neuroimaging and detection of more subtle abnormalities, it is conceivable that more athletes will be kept off the field for longer than they are now: Will this decrease the reporting of injuries by athletes?

Whatever the driving force–coercion or simply athlete motivation–misconceptions and lack of knowledge surrounding the nature and consequences of concussion add to the risk of early RTP. This topic has been recently addressed by Cusimano et al[33] who showed that nearly half of Canadian minor hockey players they surveyed did not know the protocol for RTP following a concussion. We speculate that the unobservable pathology of concussion may contribute to the erroneous lack of concern for repeat concussion. Neurorealism, a term first coined by Racine et al,[34] describes how fMRI studies can make a pathology more “real” to the public, despite lack of critical assessment. Although originally developed as part of an ethics analysis of potentially flawed societal perceptions about neuroimaging, we see that neurorealism can be used as a positive force to protect athletes. Consistent with the principle of beneficence, visual representation of injury could foster discussion and education, mitigating premature RTP, and even prevention of concussion in athletes.

Neuroimaging could also provide a quantitative assessment of microstructural damage, alleviating the complete reliance on clinical judgment of the team physician and neuropsychologist. On the surface, this technology could alleviate conflicts of interest in RTP decision making. This interpretation, however, is fraught with error if oversimplified: Indeed, caution is essential to avoid the pitfalls of neurorealism. How will physicians and coaches rationalize possibly discordant results that arise if neuroimaging findings are positive but behavioral signs negative? How will incidental neuroimaging findings be managed? We would recommend a continued reliance on clinical acumen, with neuroimaging providing supportive evidence adjunct to the clinical diagnosis. In keeping with the principle of nonmaleficence, the obligation to minimize harm, the clinician must be vigilant to avoid dangers regarding overemphasis, overreliance, and misinterpretation of imaging data.

It is still premature for imaging technologies to be used to redefine RTP guidelines, but it is neither too early to think of how the guideline might shift with neuroimaging information and what, even more acutely, will the impact be for individual athletes. How will microstructural changes be interpreted in the context of RTP? Definitions of severity and parameters for acceptance that can resist the enormous ancillary pressures from conflicts of interest, including financial loss and gain[27,35] are key challenges ahead.

Short- and long-term health effects

Dementia pugilistica or punch drunk syndrome has been long recognized in boxers following years of repeat blows to the head. There is mounting evidence, however, that repeat concussions can have short and chronic health effects on athletes practicing other forms of sport. Cognitive impairment, in the asymptomatic period shortly postconcussion,[36] and years later,[37] has been reported in football players. More concerning is the development of a dementia picture later in the lives of these athletes. Omalu et al[38] confirmed diffuse cerebral tauopathy in the autopsy of a 44-year-old retired NFL player following suicide, and similar diffuse neurodegenerative processes in the autopsies of 5 other professional athletes who committed suicide. This neurodegenerative process, termed chronic traumatic encephalopathy (CTE), can cause cognitive, neuropsychiatric, and even motor symptoms in retired athletes.

Research of CTE is still in its infancy, but the preventable environmental cause, specifically repeated head injuries,[39] gives rise to ethical discussion. Recommending that an athlete retire from contact sport has many farther-reaching implications than delaying RTP. The International Federation of Sports Medicine's code of ethics established in 1994 states "the same ethical principles that apply to the practice of medicine shall apply to sport medicine . . . Never impose your authority in a way that impinges on the individual right of the athlete to make his/her own decision."[40] However, medicine establishes guidelines for athlete protection and public health good. There are no universal recommendations, but various medical organizations have weighed in on preventing athletes from engaging in sports at high risk of concussion. In the United States, the American Medical Association has a standing order calling for a ban of boxing, while in Australia, there has been an attempt to ban boxing from the Olympics. In British Columbia, Canada, where we are based, Dr Ian Gillespie, president of the BC medical association, has called for a countrywide ban of mixed martial arts that includes boxing-like techniques.[41] By contrast, the stance of National Academy of Neuropsychology is less extreme, recommending national licensing consensus and increased neuropsychological testing for athlete protection.[42]

To what extent will newer imaging modalities affect athletes' autonomy in choice and continuation of sport? Already in 2001, compulsory brain scans were introduced by the Victorian government in Australia and within 12 months, 3 professional boxers were banned from professional fighting.[43] Should DTI also be influential in preventing an athlete from engaging in a contact sport after one or some other of still-undefined number of concussions? Currently, it is unclear how the neuroimaging data translate to CTE. Although DTI studies have shown no relation with time from injury and abnormal fiber tract findings,[11] repeat imaging of the same cohort to monitor changes over time has not been studied. Two longitudinal studies have been conducted using DTI to measure moderate to severe brain injury,[44,45] but long-term data on single and multiple concussions implementing this technology are not yet available, leaving answers to the question of the role of neuroimaging and long-term neurologic effects of concussion in sport wide open.

In the absence of firm or consistent guidelines, ethical principles are helpful in guiding risk-benefit decisions. Nonmaleficence leads to restrictions on athlete participation, in this circumstance for fear of future neurological disease. However, when compared with quality of life without sport, some risks may be worth taking, others not.[46] Indeed if all risks could be shared openly, the balance between beneficence and nonmaleficence in the context of concussion and sport could be achieved. Unfortunately, while there remains a lack of understanding of CTE and long-term or prospective diagnostic data, truly informed decision making will remain elusive. We recommend, therefore, that athletes be made aware of the potential, albeit rare risk of chronic neurological sequelae from repeat concussion,[42,47] but that the decision to restrict autonomy and retire an athlete from sport should be a clinical one, made on a case-by-case basis. There is insufficient longitudinal evidence to rely on fMRI or DTI as a biomarker to aid in this decision.

Resource allocation

Given the disparity of resources available to the professional athlete as compared with the amateur athlete, and to the athlete from a wealthy nation compared with one that is less economically privileged, achieving equitable access is clearly problematic. This ethical issue has been addressed substantially for sport in the context of gear and apparel, as well as in training.[48,49] With respect to training, for example, Canada's national swimming team modified its programs on the basis of the results of an fMRI study of the mental states of athletes post competition success and competition failure.[48,49] Kielan Yarrow and his colleagues[50] reviewed the differences in neural patterning of elite versus amateur athletes, relying on neurotechnology for elucidation of certain processes. They describe novice athletes having diffuse activation patterns, compared with elite athletes that show increased focal activation in motor planning areas, termed "neural efficiency."[50] Does this type of information significantly advantage the coach or athlete? Will the national soccer team of Uganda, a country in which a single MRI scanner exists in its capital, be disadvantaged by the absence of similar information about its own players? Indeed, one does not have to venture that far afield to ask this question; there are ample examples of resource limited regions within North America and Europe to which it applies. This use of neurotechnology in training for sport has brought age-old tensions between the have and have-nots in to a new realm: To our knowledge, for the even newer challenges surrounding neuroimaging, concussion and sport, the questions have yet to be answered. Even where knowledge transfer and exchange are at their best, practical generalizability, medical relevance, justice, and cultural acceptance will surely be tested.

Finally, expensive technologies such as MRI tax already overburdened health care systems. A consequence of the routine use of neuroimaging in sports could be an increase in private scanners or political pressure to provide more MRI through public health care.[51,52] In the United States, MRI is sold privately to consumers for screening purposes even in the absence of symptoms,[51] as are more dubious nonmedical applications such as lie detection.[53,54] Given the current pressures on health care, it is imperative to ensure that better diagnostics will lead to improved management and prognosis of disease prior to their dissemination in unproven practices.[52] Moreover, they raise questions about the need for baseline scans and related costs, and even for the costs associated with detection and management of unexpected findings.[55]

CONCLUSION

According to Lovell et al,[56] there continues to be a trend to individualize concussion management. Detection of microstructural injury through modern neuroimaging of athletes would provide a more individualized and objective test than is currently possible, and could lead to the formulation of refined guidelines in the future. Current research focused on DTI and fMRI has shown tremendous research potential to evaluate mTBI in the acute setting, bearing in mind that these studies still rely only on group data analysis. Given ongoing efforts to refine and interpret functional imaging for concussion, it is not unreasonable to predict the use of this technology clinically in the next decade. The time is now to anticipate and ask questions about how neurotechnology will impact the full range of contextual features[57] in the life of a competitive athlete including autonomy, decision making, conflict of interests, empowerment, networks of support, resources, and more. Answers today will guide the beneficent translation of the tremendous capabilities of research neuroimaging to the athlete, on and off the playing field, tomorrow.

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