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Authors	Stuart, Samuel;Hickey, Aodhan;Morris, Rosie;O'Donovan, Karol J.;Godfrey, Alan
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Opinion

Concussion in contact sport: A challenging area to tackle

Samuel Stuart [a,*], Aodhan Hickey [b], Rosie Morris [a], Karol O'Donovan [c], Alan Godfrey [a,d]

[a] *Institute of Neuroscience/Newcastle University Institute of Ageing, Newcastle University, Newcastle upon Tyne NE4 5PL, UK*

[b] *Insight Centre for Data Analytics, University College Dublin, Dublin D04 V1W8, Ireland*

[c] *School of Medicine, University College Cork, Cork T12 EH31, Ireland*

[d] *Newcastle University Business School, Newcastle University, Newcastle upon Tyne NE1 4SE, UK*

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1. The problem

The term "concussion" refers to a common form of traumatic brain injury, which typically occurs after a blow or injury to the head. It has been described as a "complex pathophysiological process affecting the brain, induced by biomechanical factors", and shear forces induced by rotational acceleration are believed to be the primary mechanism of injury in concussion.[1] The incidence of concussion in the UK has been shown to be up to 6.9 (youth) and 4.9 (adult) concussions within rugby union and up to 14.7 (youth) and 40.0 (adult) concussions within rugby league per 1000 h played.[2–4] Concussion is now seen as a public health epidemic, with clinicians seeing more occurrences, which is likely due to better symptom recognition rather than greater incidence. It has also been related to mental health difficulties and future development of neurological disorders and dementia.[5,6]

Concussion has various symptoms that can be broadly categorized as motor (e.g., balance or gait deficits) and non-motor symptoms, such as cognitive (e.g., attention, executive function, visuospatial, or memory deficits), sensory (e.g., visual, vestibular, or proprioceptive deficits), emotional, autonomic (e.g., postural hypotension or orthostatic headaches), and sleep problems. The present model for concussion management within contact sports involves a structured return-to-play, with triage assessment within the acute phase followed by attempts by clinical staff to assess various symptoms that follow such injury. The development of simple subjective paper-based pitch-side assessments of the various symptoms that present with concussion (e.g., Sport Concussion Assessment Tool, 3rd Edition (SCAT3)[7]) was a significant progression toward a standardized assessment and management process.[8] Symptoms can be evident immediately post-concussion with such pitch-side assessments. However an individual may also be subtly dysfunctional, which is more difficult to detect. Indeed, although current pitch-side assessments can detect symptoms immediately post-concussion, they have been found to be ineffective in follow-up monitoring of symptoms, with little clinically meaningful information is provided by such simple subjective measurement. This uncertainty makes return-to-play decisions difficult for clinicians as the process of structured return-to-play begins almost immediately following the initial injury, with little emphasis placed on symptom resolution before physical exertion.

Current post-concussion return-to-play criteria within contact sports do not focus on an athlete's true readiness for sport. Indeed, a recent study has shown that 60% of rugby players who returned to play within the same season as having a concussion either had a second concussion, symptom reoccurrence, or another injury.[9] This is most likely because subtle dysfunctions in motor and non-motor processes were missed without the use of sensitive objective or quantitative assessment batteries. Use of more specific assessments may help track concussion symptoms resolution. For example, the vestibular, ocular motor screen[10] monitors more subtle concussion related deficits that can be detected within eye-movements (saccades, smooth pursuits, *etc.*), and are linked to cognitive, visual, and motor processes. However these more specific subjective clinical questionnaires and assessment batteries require highly skilled clinicians (i.e., neuropsychologists) and offer only a one off "snapshot" of a player's capability (i.e., neurological function), with little focus on the variability of individuals' outcomes both pre- and post-concussion. Return-to-play decisions are further complicated by the differences in reported concussion recovery timescales for sport and other injury mechanisms. For example; current return-to-play within rugby union states that 3–4 weeks is necessary for symptom resolution,[11,12] whereas evidence from road traffic accidents states that 6–12 months is required.[13,14] Clinicians within sport environments are therefore left with difficult post-concussion decisions.

Pitch-side assessment and long-term recovery monitoring are limited at present by a lack of baseline assessments, which is

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* Corresponding author.

E-mail address: sam.stuart@ncl.ac.uk (S. Stuart)

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largely due to expense but limits a clinician's diagnostic framework to categorize a player's normal capability. Computerized cognitive assessment batteries, such as immediate post-concussion assessment and cognitive testing (ImPACT),[15] have become the "gold standard" for cognitive examination following concussion and are used to monitor recovery to age-matched "normal" scores. However athletes (particularly professionals) likely require individualized normative data to ensure a return to their normal function. Such batteries are limited as visual, vestibular, and proprioceptive deficits following concussion in contact sports are not examined or studied. Similarly, the long-term impact of concussion has been poorly investigated with few studies examining the long-term follow-up within contact sports. Typically, studies have involved health problems of older adults being correlated with questionnaire results regarding previous concussion when playing sport, which likely provides inaccurate or biased results.

Overall, concussion within contact sports is fast becoming a focus for research in order to overcome the discussed limitations within current practice. To establish both short- and long-term effects of concussion within contact sports, more focus must be placed on the development of multiple component assessments that cover a range of symptoms that may present following a concussion.

2. Role of modern technology

Technological applications are at the heart of many current investigations to provide accurate objective measures of a variety of symptoms that can be performed by clinicians at pitch-side and beyond.[16] To date, objective analysis of motor function post-concussion has largely been carried out by highly trained staff with expensive equipment such as 3-dimensional (3D)-Motion capture or force-plates for measurement of primarily motor deficits, such as gait or postural control impairment.[17,18] These assessments are usually carried out within an allotted time period (24–48 h to 7 days, most prominent symptomatic period) following a clinically diagnosed concussion and rarely involve comparison to a baseline measurement, largely due to expense and lack of standardized practice. Such assessments are therefore not accessible to those involved in contact sports and are unfeasible (and perhaps not applicable) for pitch-side assessment. Therefore any results from such assessments should be interpreted with caution.

Currently, application of inexpensive modern wearable technology ("wearables") is being investigated for a multitude of health-related diagnostics. For example, mobile-phone based technology has been investigated for diagnosis of neurological conditions (i.e., Parkinson's disease).[19] Smartphones may serve as a simple device for clinicians to monitor and engage with players pre- and post-concussion, as these provide the opportunity to develop applications that can continuously or intermittently measure a variety of motor and non-motor processes. Such applications could be used to measure immediate symptoms similar to traditional pitch-side assessments, but could also store information and monitor how individuals progress with standardized and robust assessments. Other non-invasive wearables, fabricated with accelerometers, gyroscopes, and global positioning systems,[20,21] are being employed at various body locations to investigate numerous micro-level aspects of player performance at pitch-side (e.g., balance, player pitch movement, *etc*.). These objective devices are being used to measure static and dynamic balance through the recovery phases, which may provide a simple and useful means of monitoring recovery. However, to date application of wearables in concussion assessment has been limited as such technology currently provides little real-time data, lacks insight into specific within-game collisions or contacts, does not involve non-motor symptom assessment, and there is also a lack of "gold standard" for wearable location or data processing and analysis.

3. Future research

Further research is required to address the current concussion assessment and management needs within contact sports, which will aid clinical decisions for short- and long-term player recovery. Development of low-cost wearable technology for clinical use that can capture both motor and non-motor performance at baseline, pitch-side, and beyond is paramount.

New devices could monitor motor and non-motor symptoms, by tracking eye-movement, cortical activity, postural control, gait, or cognitive performance similar to current research grade devices, like eye-trackers, electroencephalogram (EEG),[22] functional near infra-red spectroscopy (fNIRS),[23] accelerometers,[24] *etc*. For example, traditional and robust cognitive assessments (e.g., ImPACT battery) could be transferred into smartphone or tablet technology for use within all stages of injury recovery. This could be combined with eye-tracking through smartphone cameras and could be remotely monitored by clinicians who could increase test batteries difficulty dependent upon recovery stage. Newly developed mobile cortical activity monitors (EEG, fNIRS, *etc*.) could be synchronized with employed smartphones or tablets and worn while such cognitive batteries are performed by players, which would allow for thorough evaluation of cognitive and cortical function. Similarly, smartphone accelerometers may provide measurement of motor performance, such as gait, balance, and physical activity.

Technological implementation within contact sports with low-cost wearables would allow for comprehensive objective monitoring within amateur and elite sport. Technology could allow clinicians to remotely monitor player recovery and store a history of performance statistics to allow for individual variance. Once a variety of technologies have been both validated and implemented within contact sports, we can examine specific measurements for the most robust variables for concussion diagnosis, management, and recovery. Another possibility is that technology could move concussion care away from a single point of contact (i.e., often only 1 assessment by A&E medic or neurologist for final return-to-play decision) to a multi-disciplinary team (i.e., medic, physiotherapist, neuro-psychologist, *etc*.) who have access to a variety of player performance metrics over time. Despite potential of new technology, it is likely that a number of outcomes (both subjective and objective) will be required to assess and manage concussions in contact sport, which will always include clinical assessments. However, application of

modern wearable technology will provide clinicians with vital information that may reduce player risk of future injuries or long-term neurological issues.

Authors' contributions

SS conceived of the article ideas and design and drafted and revised the manuscript; AH, RM, and KO revised and edited the manuscript; AG participated in its design and coordination and helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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