Exploratory Analysis of the effects of University Rugby on Brain Health monitored via a Somatosensory Device

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Abstract

Background: Rugby has the highest incidence of Sport Related Concussion of any contact sport. Despite considerable media interest and research, the underlying relationship between participation in rugby union and the manifestation of concussion is poorly understood. To address this problem, novel, non-invasive technologies have been developed to measure brain health in a quantative and real-time manner. These technologies include the 'Brain Gauge somatosensory system' which provides a diagnostic system for overall brain health.

Aim: For the first time, the Brain Gauge was used to monitor and measure brain health amongst a group of five University rugby players over the course of six games during the 2017/2018 playing season. An unmatched group of four non-rugby playing University students were used as controls.

Methods: The Brain Gauge technology was used to measure: Reaction Time (RT), Sequential (SEQA) and Simultaneous Amplitude Discrimination (SIMAD) and Reaction Time variability (RTVar). The raw data underwent statistical analysis to test for differences within and between individuals and for changes across the six-week testing period. In addition, the Rivermead Post Concussion Questionnaire was used to monitor changes in symptoms across the 6 week testing period.

Results: There were significant differences between individuals for three of the four brain health (RT, SIMAD, RTVar) measurements. In contrast only one of the four brain health measurements (SIMAD) displayed statistically significant changes over the six-week testing period. Pairwise correlation analysis detected strong correlations between RT and RTVar together with the following symptoms from the Rivermead Questionnaire: nausea (0.95), fatigue (0.90), feeling depressed (0.93) and poor memory (0.95).

Conclusions: The Brain Gauge somatosensory system accurately measured fluctuations in brain health and provided quantative baseline data to support future studies. Further research is required to establish the causal relationship between brain health, concussion and participation in University rugby union.

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1 Introduction

Direct impacts to the head or neck have been proposed as significant contributing factors to mild traumatic brain injuries such as concussion (King et al. 2003). Concussion associated with sports is commonly known as Sports Related Concussion (SRC) and is defined as '*a traumatic brain injury induced by biomechanical forces'* (McCrory *et al.*, 2017; Powell, 2017). The incidence of SRC is increasing at an alarming rate globally and is now considered a major risk to players participating in contact sports such as Rugby Union where tackling between players is common and permitted (McKee *et al.*, 2009; Spiotta *et al.*, 2011; Johnson, 2012; Jordan, 2013; Mez *et al.*, 2017). This increased risk of injury can be explained by the distribution and absorption of energy within contact situations such as tackling which is a major factor in contact sports such as rugby. Recent published literature has identified that the frequency of injury in contact sports such as Rugby Union is approximately 87 per 1000 player hours and therefore represents one of the largest incidences of concussion in any contact sport (Palmer-Green, Trewartha and Stokes, 2008; Gardner *et al.*, 2014; Rafferty *et al.*, 2018)

When SRC is diagnosed and treated early and in a timely manner the adverse effects of SRC such as cognitive, balance and symptoms deficits (Broshek, De Marco and Freeman, 2015; D. A. King, Hume and Tommerdahl, 2018) can be resolved within 10 days of rest. However, during the period between concussion and full recovery, it is critical that the player does not receive a second concussion. If a player does sustain a subsequent concussion, whilst they are recovering, the injury can have serious consequences including death. Such an injury is referred to as Second Impact Syndrome (SIS) and often results from the same individual receiving another impact shortly following the first impact without adequate time for the individual to recover (Marshall and Spencer, 2001; Giza, Prins and Hovda, 2017). This results in an injury with potentially severe consequences, including increased intracranial pressure and in extreme cases death (McKee *et al.*, 2009).

The large heterogeneity in progression of symptoms and recovery times from concussion makes it very difficult to accurately and objectively monitor and track concussion and determine when it is safe to return to normal activity or sport. As a consequence, there is currently no objective or 'gold standard' method of diagnosing or monitoring recovery from concussion (McCrory *et al.*, 2017).

Novel and new disruptive technologies such as somatosensory devices have been developed to measure and monitor the central nervous system and provide promising avenues to measure in a non-invasive way subtle changes in brain function and health (Tommerdahl, Favorov and Whitsel, 2010; D. A. King, Hume and Tommerdahl, 2018). This has led to the application of the Brain Gauge somatosensory assessment (D. A. King, Hume and Tommerdahl, 2018) to monitor differences between concussed and non-concussed individuals and their recovery.

The growing number of SRC in both professional and amateur rugby has prompted closer dialogue between academia and health bodies regarding the safety and welfare of players participating in contact sports. In addition, a greater awareness and surveillance of SRC has highlighted the difficulties of accurately diagnosing SRC in a timely manner, particularly during matches or immediately after competition. Hence without an accurate agreed and robust 'gold standard' for diagnosis of concussion there is a significant risk that many concussions are missed resulting in a major risk to player safety and welfare.

In response, there is a growing awareness and concern as to the risks within rugby union posed to players suffering SRC. This has led to governing bodies releasing guidelines to support the identification and symptoms of SRC. These include: World Rugby "Recognise & Remove" and the Rugby Football Union's "Headcase" initiative (World Rugby, 2018). These guidelines aim to promote timely recognition of concussion in players and subsequent removal from play to avoid further danger to players. Beyond professional sport, there is also increasing concern surrounding the risk of traumatic brain injury to adolescent and youth players undertaking contact sport (Powell, 2017).

Research has shown that children and adolescent athletes: are more susceptible to concussion, take longer to recover; and may have more significant injuries arising from Second Impact Syndrome (McCrory *et al.*, 2017).

At the professional level, reviewing the incidents of suspected SRC has been made easier with the use of slow motion video. In addition, the introduction of Head Injury Assessment (HIA) protocol allows adequate time out of the game for assessment of players by independent physicians to make more informed decisions regarding diagnosis of SRC. This has served to increase the likelihood of timely and accurate diagnosis and the appropriate medical intervention or treatment (McCrory *et al.*, 2017; Powell, 2017).

However, outside of professional rugby, the level of medical support has declined relative to the professional game. Without adequate medical support compared to their professional counterparts, adolescent and amateur athletes are at an elevated risk of having SRC diagnosis delayed or missed entirely. Hence, there is a significant need to objectively assess if there are any risks associated with players participating in University Rugby Union where the availability of medical support is less than that which is available at the professional level.

This study will monitor levels of mental acuity in a sample of University rugby players over a six-week period by utilizing a somatosensory system that measures mental acuity or brain health. The potential of using a multi-parametric visualization approach to monitor the effect of University rugby on brain health will also be assessed.

The observations, data and findings emerging from this study have direct relevance and implications for the physiotherapy profession, particularly sports physiotherapists. Typically, physiotherapists are directly involved in the communication and management of individuals during their recovery from a concussive injury, where critical decisions by doctors are taken regarding when players should be allowed to return safely to resume playing. Methods that support accurate and objective diagnosis of concussion and subsequent recovery will enhance treatment protocols and general safety of players involved in contact sport.

More generally a quantitatively robust, low cost and reproducible approach to measure brain health in a range of different environments will have broad applications across the clinical, allied health sciences and sports medicine professions including opportunity to remotely monitor recovery from concussion.

2 Literature Review

Despite the focus and emphasis of research on injury associated with contact sport, the risk of injury remains high, particularly in Rugby Union (Palmer-Green et al. 2008 Cunningham et al 2008). This has led to the belief that injury is 'part and parcel' of playing contact sports and players will recover with no long-term negative adverse effects.

However, researchers at the turn of the millennium suggested that there may be a more serious and detrimental underlying 'hidden epidemic' associated with participation in contact sports. Marshall and Spencer (2001) highlighted the harmful irreversible effects of participation in contact sports and in particular the problem of undiagnosed mild traumatic brain injury or Sports Related Concussion (SRC).These observations and conclusions arose from decades of biomechanical data collection arising from head impact in contact sports such American Football and Rugby. In parallel with these investigations, a significant number of case studies had also been published, which examined the cadavers of retired and deceased NFL players. On examination, it appeared that many of these sportsmen displayed large structural abnormalities within brain tissue and signs of Chronic Traumatic Encephalitis (CTE). These structural abnormalities have been proposed to result from their involvement in American football where biomechanical data has highlighted the exposure of players to massive physical forces (Baugh *et al.*, 2012; Mccrory *et al.*, 2013; Mez *et al.*, 2017).

These inter-connected trends and observations have raised many questions regarding the safety of players participating in contact sport. This literature review aims to present the current knowledge of concussion related risks associated with contact sports and secondly the evolution and development of novel, non-invasive technologies to monitor brain health as surrogates for the detection of concussion in contact sport.

2.1 Exploring the Risks Associated with Participation in Contact Sports

Over the past five decades, large strides have been made in the collection of biomechanical data relating to head impacts across a variety of contact sports (Moon, Beedle and Kovacic, 1971; Reid *et al.*, 1971; Rowson *et al.*, 2009; Baugh *et al.*, 2012). As far back as 1970, advancements in the design and instrumentation of accelerometers in helmets provided opportunity to monitor head acceleration data for athletes during games. These technological advances enabled the magnitude of force exposed to the heads of athletes to be estimated. Crucially these were restricted to only those games that allowed or required the wearing of helmets, therefore games such as Rugby Union did not benefit from these interventions. These seminal studies did however lay the foundation for investigations into the quantification of the potential risk associated with contact sport and brain injury (Moon, Beedle and Kovacic, 1971; Reid *et al.*, 1971). Subsequently research carried out within the National Football League (NFL) has allowed the retrospective quantification and construction of 31 impacts to the head from game video footage (Pellman *et al.*, 2003; Rowson *et al.*, 2009; Crisco *et al.*, 2011). Of these 31 impacts, 80% were concussive and enabled the researchers to develop injury risk curves for mild traumatic brain injury (Rowson *et al.*, 2009; Powell, 2017).

Nominal values for brain injury were found to be 98g of linear acceleration and rotational acceleration of 6432 (rad/s^2) (Pellman *et al.*, 2003; Baugh *et al.*, 2012). In comparison, non-helmeted sports such as youth female soccer, have identified peak acceleration of 63g and 8869 rad/s^2 (Baugh et al. 2012; Hanlon & Bir 2012). Within this study there were no reported concussions. However, the absence of a rigorous protocol for the detection of concussion makes it difficult to rule out the occurrence of concussion within this study (Powell, 2017).

A pivotal paper published by King et al (2015) investigated the magnitude and frequency of head impacts sustained by one amateur rugby-union team in New Zealand utilizing accelerometer mouthguards. To our knowledge this was the earliest study to use accelerometer mouthguards which measured impact data in

amateur Rugby Union. King et al (2015) identified more than 20,687 impacts greater than 10g over the duration of the study.

Unexpectedly, the average amount of impacts per game (77) is considerably higher than other published data (18 per game) for American College Football (Rowson *et al.*, 2012).

Overall these empirical results reinforced the hypothesis that the forces vary with the type of sport played. The contrasting style of play and the use of protective equipment in American Football makes cross comparison between sports such as rugby difficult to draw robust evidence based conclusions. Furthermore, there are also experimental difficulties that limit the veracity and utility of the published results. These include experimental error (10% error for linear and rotational acceleration) and saliva that sometimes renders impacts non-detectable. These factors contribute to incomplete data sets and reduces the overall impact of the studies to real world situations.

The limited availability of reproducible data, makes it difficult to establish the precise relationship between the force of impact and the likelihood of Sports Related Concussion (SRC). This is further confounded by the suggestion that individuals differ in their susceptibility to concussion and is further influenced by gender, weight, and previous exposure to concussions (King *et al.*, 2015). These factors may serve to help explain why the identification of a specific threshold level of impact, known to induce concussion has proven too difficult to define (Martini *et al.*, 2013; McCrory *et al.*, 2017).

As a consequence, definitions stipulated by the Concussion In Sports Group (CISG) do not provide any differentiation in the severity of the injury nor any further understanding of the intrinsic processes that may be associated with SRC (McCrory *et al.*, 2017). Rather, a set of common features or symptoms are provided to medical staff attending games that can be used to identify concussive head injuries. These include: headaches, general pain loss of consciousness, balance and cognitive deficits making the definition of SRC even more challenging and subjective with a major burden of responsibility being placed on clinical judgement (McCrory *et al.*, 2017). Although biomechanical data has provided an important initial contribution to our understanding of the type and nature of forces

involved in SRC there is no agreed quantitative metric assigned to measure impact induced SRC. Thus, individual management and return-to-play decisions are undertaken by medical professionals who rely solely on clinical judgement (Mccrory *et al.*, 2013; McCrory *et al.*, 2017).

This has serious implications for the management and safety of players. Without fully understanding what level of force is associated with concussion it makes it very difficult to: a) mitigate the risk b) recognise players who may be at risk or indeed have suffered a concussion c) objectively and safely assess when a player is safe to return and participate in sport. This is hugely challenging to players, coaches, medical staff, administrators and parents who are becoming increasingly aware of the risks associated with SRC. These factors have prompted further and more innovative approaches to measure brain health and to provide accurate and high-resolution methods to assess and track neurological disorders that include concussion.

2.2 The Concept: Non-Invasively Assessing Brain Health

Despite the considerable emphasis and research into the underlying causes and factors influencing concussion, little progress has been made in our understanding and subsequent diagnosis of concussion. Current contemporary methods for assessing neurological disorders such as SRC are often inadequate due to poor accuracy, lack of portability, high cost and the inability to generate high resolution data to support objective decision making or diagnosis (Patton, 2016; McCrory *et al.*, 2017). In the last decade, development of devices such as the Brain Gauge (Corticalmetrics, 2018) have provided novel approaches to asses brain health.

The concept takes advantage of the direct connection between a patient's skin and the cortex within their brain. This creates a measurable sensory signal that results from interactions between specific areas within the brain that are activated by stimulating the skin. Both human and animal models have been used to demonstrate a significant correlation between sensory percept in humans and patterns of brain activity (Tommerdahl, Favorov and Whitsel, 2010).

This research has been extended to include a number of neurological conditions that include concussion (Lovell *et al.*, 2003; Tommerdahl, Favorov and Whitsel, 2010; Tommerdahl *et al.*, 2016).

2.3 The Brain Gauge – a 'Vital Sign' for Brain Health?

The causes of hypertension are complex with many different factors contributing to the condition. However, measuring a patient's blood pressure is often considered highly accurate, cheap and an accurate estimate of an individual's health. Hence, vital signs are a well-established feature and accurate predictor of the health status of a patient (Handler, 2009; Wieling and Schatz, 2009). Somatosensory devices have been proposed as a potential future equivalent 'vital sign' for a patient's brain health (Tommerdahl et al. 2018). This is due to sensory percept relying on many features crucial to the central nervous system (CNS) to perform habitual activities. In addition, an intact peripheral nervous system is required for signal transmission to the spinal cord. Lastly, the cerebral cortex which is involved in high level processing of signals has to be able to spatially and temporally integrate information which it has received. This requires numerous points of processing in both sensory aspects of the cortex and higher-level function.

For these reasons the somatosensory system as described by King et al (2018) is ideally positioned to be used as a diagnostic system for the CNS. Firstly, the design of the somatosensory system means that areas of the skin correspond to specific regions of the cortex in a reliable manner.

Vibration of two adjacent finger-tips, stimulates brain activity in two adjacent cortical regions that have been shown to interact in a predictable fashion. Ambient environmental noise in the somatosensory system can be controlled during the testing period. Furthermore, the somatosensory system is the only sensory system that has been shown to be highly integrated with response to pain, and this is highly relevant to SRC, where pain is often reported (Trahan *et al.*, 2001; Martin *et al.*, 2017). More generally, brain physiology studies over the past century have shown that cortical-cortical interactions play a significant role in sensory perception. This means adjacent and adjacent neuronal assemblies interact with one another and these interactions result in distinct percept's. For example the Nobel prize winner Georg von Békésy was the first to describe *lateral inhibition*, the means by which active neurons inhibit the activity of the cortical neuronal assemblies surrounding them (von Békésy, 1959).

It should be noted that von Békésy developed this hypothesis or concept based on sensory perceptual experiments. In other words, an important neurophysiological mechanism was characterized simply by measuring an individual's perceived response to sensory stimuli. In subsequent decades, neurophysiological experiments – including those conducted by Tommerdahl et al (2010) who demonstrated the concept of lateral inhibition (Tommerdahl, Favorov and Whitsel, 2010). Sensory perception also provides a platform for high resolution analysis of brain health which is highly relevant to SRC. One example of a sensory perceptual test is the eye chart – most people can be prescribed lenses based on a simple and basic eye exam using an eye chart. A high degree of corrective optical precision is attained by this simple sensory perceptual test and verbal interaction with the patient. Similar opportunities exist for the adoption of inexpensive somatosensory technology to measure and monitor various aspects of brain health without the need to deploy expensive and invasive imaging technology. For example, most people can differentiate a change of 'between 10 and 20%' in the intensity of stimuli on adjacent fingers as described by Weber's Law (Francisco et al. 2008; Tommerdahl et al. 2010,Tommerdahl et al. 2018). Currently no imaging procedure or devices would be able to detect such differences in cortical response and would also require the involvement of highly trained specialists. In this context, the Brain Gauge is a timely and important development that can assess an individual's brain health easily and accurately and is sensitive to a number of neurological disorders including SRC.

An increase in the production of testing instruments has resulted in a reduction in price of the testing units, allowing more widespread use in the allied health professions and sport. Greater accessibility to somatosensory devices will open up new opportunities for deployment in a range of new situations and environments including patient recovery and/or response to treatment that can be monitored remotely.

Somatosensory devices are attracting considerable interest from the research community who are assessing the role of this technology in monitoring mental acuity. For example, a recent case study published by King et al 2018 analysed and described the utility of the Brain Gauge in monitoring the recovery of a single

patient with concussion. The research demonstrated that a multi-parametric measure of cortical metrics was related to patterns of recovery and the range of symptoms displayed by the patient who sustained a mild head injury after falling off her bicycle.

The application and deployment of somatosensory devices in rugby union and other contact sports is in its infancy. As outlined in the Introduction there is a pressing need to better understand the relationship between playing rugby and the incidence of SRC. Despite the growing interest in this topic there has been no formal structured analysis of the risks to brain health associated with participation in University rugby.

Rugby is a popular University sport for both men and women where the incidence and risk of SRC has not been comprehensively studied. As such it provides an ideal test bed to explore the utility of low cost somatosensory technology to monitor brain health of rugby players during the playing season. Without adequate medical support and monitoring, University rugby players may be at an elevated risk of concussions being missed or undiagnosed, which represents an elevated risk to University rugby players.

Therefore, there is a demand to develop; low cost and objective methods for monitoring brain health across individuals and teams which can be readily employed by Universities and players.

2.4 Aims of the Research

Critically evaluate the potential of the Brain Gauge somatosensory technology to systematically monitor changes in aspects of brain health in University rugby players.

Objectives

1. Evaluate the practical role of Brain Gauge somatosensory technology to measure and monitor aspects of brain health and function over a six-week period for a sample of male University rugby players.
2. Discuss the opportunities to incorporate data from Brain Gauge somatosensory assessment tool to support Physiotherapists and medical staff in making informed decisions on the management of Sports Related Concussions in University rugby.

3 Methodology & Approach

3.1 Experimental Design

This project represents an exploratory study of the effects of University Rugby on brain health assessed via a novel neurosensory based method during the 2017/2018 rugby season. The study measured five male rugby players (Mean age 21.40 ± 1.02 years, height, 185.00 ± 7.15 cm, body mass, 84.75 ± 11.86 kg) across approximately 6 games. In addition, four inactive controls (mean: age 24.75 ±1.29 years, height, 181.12 ± 6.73 cm, body mass, 95.40 ± 12.48 kg) were also included who were not currently participating in Rugby Union or any other contact sport. The inclusion criteria for the study is that all players are to be full-time undergraduate and postgraduate students.

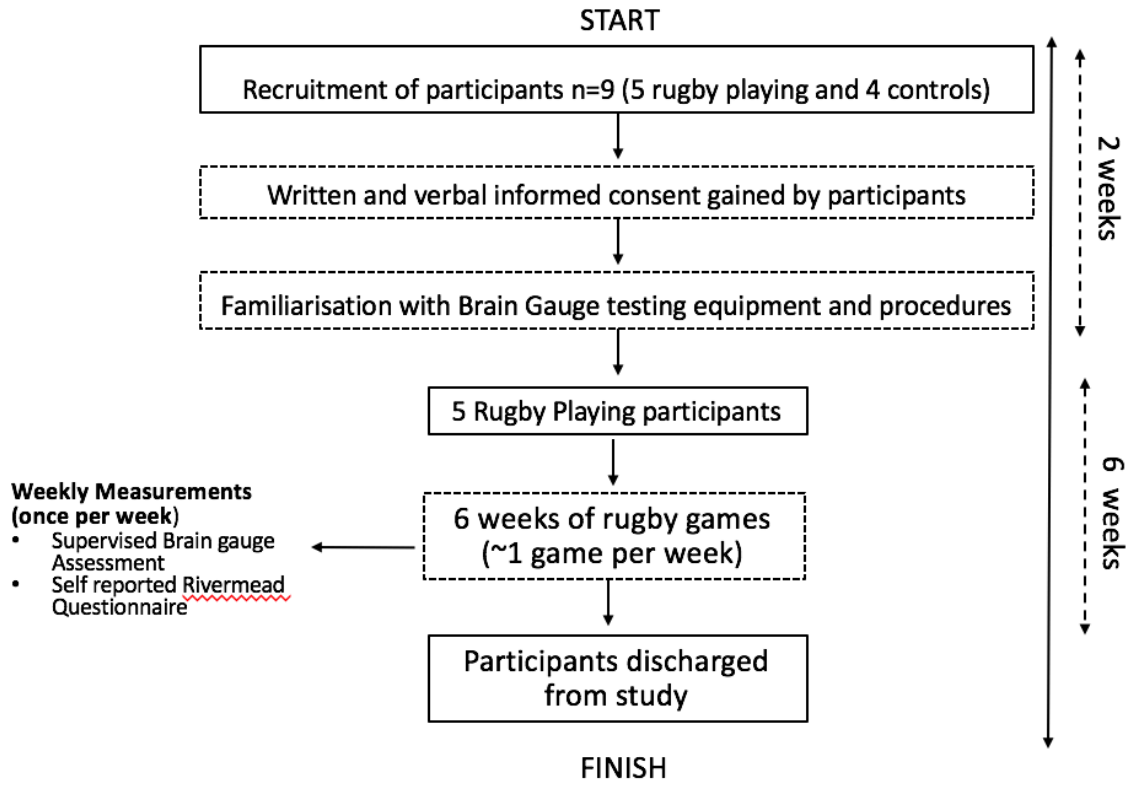

Figure 1 Protocol Schematic of Study Design.

3.2 Participant Recruitment

A higher education institution was selected based upon the practical needs of data collection. The whole performance rugby squad were asked to participate in the study based on a volunteer sample cohort. A full debrief and associated information was provided to the whole squad and only those who volunteered to take part were included in the study. Potential participants were given the researcher's email address and those who were interested in participation asked to email the researcher after 48 hours to provide enough time to make an informed decision.

3.3 Data Collection

A mobile and non-invasive tactile stimulator, the Brain Gauge device (as shown in Figure 1) was used to deliver stimuli to adjacent fingertips (2^{nd} and 3^{rd} digit) of participants left hand (Francisco *et al.*, 2008; Tommerdahl, Favorov and Whitsel, 2010). By exploiting the somatotopic relationship that exists between the skin and cortex, biologically based hypothesis driven protocols have been designed (Corticalmetrics, 2018) to investigate changes that occur with cortical-cortical interactions. It has been shown that these interactions are altered by neurological trauma such as mild Traumatic Brain Injury (mTBI) or concussion. This allows changes in sensory perception to be readily and efficiently measured and carried out within a series of tests (~3 minutes per test), which equates to a total battery of tests taking between 15-25 minutes. For the convenience of testing players within the limits available for this study, a shortened test of approximately 8 minutes was used for the testing battery. The testing occurred at a mutually convenient time every week during the course of the study to allow short term effects in addition to seasonal effects to be measured. No data was shared outside of this study, to eliminate any potential conflicts of interests that might affect player selection decisions.

3.4 Brain Gauge Somatosensory Assessment Procedure

As previously described by King et al (2018) the Corticalmetrics programme runs participants through the battery of testing. The battery of tests lasted approximately 8 minutes from start to finish and is completed with participants sat down at a laptop. The two probes on the Brain Gauge device provide a stimulus through vibration (25-50hz) for participants index (D2) and third (D3) fingers. The participants are then asked to respond by pressing their D2 and D3 according to the specific test undertaken.

Figure 2 Brain Gauge Somatosensory Device

The 6 measures calculated by the Brain Gauge technology are: Speed, Accuracy, Plasticity, Focus, Fatigue and Corticalmetric. The specific calculations are displayed in Appendix 1. The raw output data for Reaction time (RT), Sequential and Simultaneous Amplitude Discrimination and Reaction Time variability were also analysed. The SPSS statistical software package was used to analyse the data generated.

3.5 Additional Measures

Subjects underwent baseline height (cm) and weight (kg), testing at the start of the study. Alongside these measures the number of minutes each player has participated in BUCS rugby was also recorded, to ensure consistent participation in rugby union. All 5 experimental participants played a full 80 minutes of Rugby Union throughout the 6 weeks of rugby games.

Multiple mental acuity measures together with responses to a detailed questionnaire (self-report Rivermead) was also included in the analysis to support the study. Throughout the testing protocol no concerns were raised regarding player welfare including abnormal findings on the Brain Gauge test scores and or the Rivermead questionnaire.

3.6 Statistical Analyses

The data collected include both interval and ordinal data, resulting in a data set representing information across multiple individuals and time (weekly intervals). This allowed variation within and across individual to be analysed. All data was analysed with the SPPS statistical software package and presented in the form of Linear Regression, paired t-tests, Analysis of Variances (ANOVA) analyses and Pearson's Correlation matrices.

3.7 Ethical Considerations in the Study

Although this study was largely observational in nature, researchers have a duty of care to raise any concerns where results indicate that participants may be at risk of significant harm. To mitigate the risk of harm to participants, it is important that all potential adverse findings to participants are reported to those responsible for their medical care. Since this study utilised a novel technology and approach which has not been tested using University rugby players it is difficult to quantify what represents an abnormal observation. However, it was agreed that any Rivermead Questionnaires which were scoring highly, or any large changes in Brain Gauge (adversely) scores would result in appropriate action to alert University staff and/or medical professionals. This was not required during this study, with no concerns raised by any participant's scores or symptoms.

4 Results

4.1 Descriptive Statistics

Nine individuals were assessed for four measures of mental acuity over a 6-week period during their rugby playing season (2017-2018). Five of the individuals were active rugby playing participants, while four of the individuals who were not involved in rugby related activities were utilised as controls.

Measures were obtained using the Brain Gauge somatosensory assessment and the data is summarized below in Table 1. The full data obtained with the brain–gauge assessment tool is provided in Appendix 1. Table 1 shows a summary of the mean and standard deviation for each of the participant across four measures of mental acuity. The results demonstrate wide variation between individuals for each specific measure. For example, a threefold difference in reaction time variability (RT variability) was observed between participant C and D and a fourfold difference in simultaneous amplitude discrimination was observed between participant D and E.

Table 1 Summary Statistics for four measures of mental acuity gathered by the Brain Gauge somatosensory device expressed as Mean +/- Standard Deviation for each participant together with four controls.

	Reaction time A (RT) milliseconds		Reaction time B (RT) milliseconds		RT variability A		RT Variability B		Sequential Amplitude discrimination (microns)		Simultaneous Amplitude discrimination (microns)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Participant A	319.23	11.93	327.43	27.75	25.18	09.08	31.10	11.14	42.17	28.95	58.50	12.70
Participant B	267.73	13.45	270.95	09.73	21.60	16.70	18.35	05.84	48.25	15.71	46.25	26.21
Participant C	204.72	15.01	205.04	24.85	11.40	03.77	18.60	09.95	35.20	24.30	35.00	13.39
Participant D	222.32	10.64	222.24	12.25	34.50	05.00	17.06	04.59	68.00	19.29	86.40	18.93
Participant E	173.15	13.85	177.27	13.44	14.32	04.97	41.90	65.77	41.00	24.45	19.83	09.21
Control A	270.80	11.00	237.50	29.30	33.10	08.60	15.40	06.5	27.00	06.00	70.00	14.00
Control B	205.60	14.20	208.30	08.10	16.55	02.85	18.85	03.75	40.50	04.50	66.00	10.00
Control C	289.50	25.50	257.70	24.10	16.70	07.70	14.95	03.65	30.00	19.00	22.00	11.00
Control D	173.20	02.60	176.2	4.60	04.45	00.25	13.34	01.75	34.50	21.50	88.00	24.00

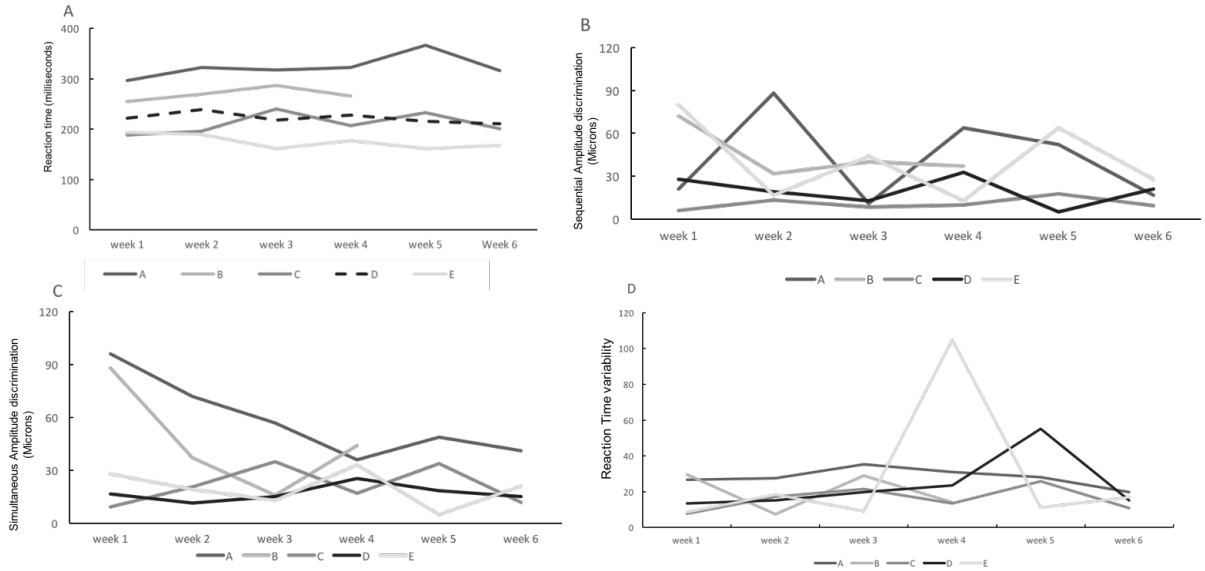

Figure 3 Individual differences in measures of mental acuity across 6 weeks. Panel A corresponds to Reaction time, Panel B corresponds to Sequential Amplitude Discrimination and Panel C Simultaneous Amplitude Discrimination. Panel D corresponds to Reaction Time variability.

Individual differences for each of the five participants is displayed graphically in Figure 1 for Reaction Time (Fig 3A), Sequential Amplitude Discrimination (Fig 3B), Simultaneous Discrimination (Fig 3C) and Reaction Time Variability (Figure 3D).

4.2 Reaction Time (RT)

Using the full dataset, an analysis of variance (ANOVA) identifed statistically significant inter-participant differences for Reaction Time [$F(8)=107.999, p<0.001$]. However, only one individual was identiifed with a statistically significant difference when directly comparing rugby and non rugby playing participants, a one-way multivariate analysis of variance (repeated measures) was conducted to determine whether there was a statistically significant difference in Reaction Time (RT) over the six-week period of assessment. Two measures of reaction time were assessed; Reaction Time A and Reaction Time B. Initial quality control, via the visual assessment of a boxplot and a Shapiro-Wilk test ($p > .05$), discovered no outliers and confirmed the normality of the data distribution.

Mean (+/- Standard Deviation) RT increased from week 1 (224.97 ± 49.76 milliseconds) to week 2 (231.63 ± 61.68 milliseconds) and week 3 (235.85 ± 64.22 milliseconds).

In week 4 RT decreased (233.43 ± 62.47) then rose sharply in week 5 (247.70 ± 85.59 milliseconds) and finally decreased in week 6 (223.75 ± 63.98 milliseconds). Despite these trends, the differences in RT across time for the combined dependent variables were not statistically significant, *[F (10, 28) = 0.615, p = .788; Wilks' Λ = .672; partial η2 = .180]*.

4.3 Sequential Amplitude Discrimination (SEQA)

In contrast to Reaction Time, no statistically significant differences between participants for Sequential Amplitude Discimination (SEQA) [*F(8)=0.9845, p=0.435*]. In addition, a one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in SEQA over time. There were no outliers in the data, as assessed by inspection of a boxplot. SEQA scores were normally distributed at each time point, as assessed by Shapiro-Wilk's test (*p > .05*). Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, *χ2(14) = 22.47, p = .088*. Based on the mean ± standard deviation data presented in Fig 3B, SEQA decreased consistently from week 1 (39.90 ± 24.74 microns) to week 2 (38.00 ± 25.90 microns), week 3 (30.90 ± 26.76 microns) week 4 (21.55 ± 21.60 microns), week 5 (36.58 ± 37.15 microns) and week 6 (21.40 ± 23.56 microns). However, no statistically significant differences in SEQA over time were detected [*F(5, 40)= 1.27, p = .296*].

4.4 Simultaneous Amplitude Discrimination (SIMAD)

For Simultaneous Amplitude Discimination (SIMAD) there were no statistically significant differences between participants [*F(8)=2.98, p=0.013*], when the full dataset was analysed. However, seperate analyses including only the rugby playing participants detected statistically significant inter-participant differences [*F(4)=4.356, p=0.00968*]. In contrast, there were no statistically significant inter-participant differences between non-rugby playing control participants [*F(3)=1.629, p=0.2505*].

This suggests that variance in SIMAD is greater in rugby players than non rugby playing participants, and that these two groups should be considered separate for future analyses.

The ability of the SIMAD metric, which measures one's ability to accurately determine which of two stimuli is larger in size (amplitude), to discriminate between between active rugby players shows promise of the technology to detect differences in mental acuity as a result of physical strains experienced during rugby matches. However, the lack of varaition in SIMAD scores for the non-rugby playing controls limited the ability to separate experimental from control participants.

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in SIMAD over time. Initial quality control, via the visual assessment of a boxplot and a Shapiro-Wilk test ($p > .05$), discovered no outliers and confirmed the normality of the data distribution. However, the assumption of sphericity was violated, as assessed by Mauchly's test of sphericity, $\chi 2(14) = 31.71, p = .007$. Therefore, a Greenhouse-Geisser correction was applied ($\varepsilon = 0.432$). The modified one-way repeated measures ANOVA detected statistically significant changes in SIMAD over time, with SIMAD in week one (64.22 ± 31.72 microns) decreasing in week two (52.33 ± 25.38 microns), week three (51.78 ± 40.11 microns), week four (36.11 ± 34.74 microns), week five (23.58 ± 30.41 microns) and week six (20.09 ± 24.03 microns. The ANOVA detected a statistically significant difference at the 5% level [*F(2.160, 17.278)=3.846.p=0.039*].

4.5 Reaction Time Variability (RT variability)

For Reaction Time (RT) variability statistically significant differences were found when analysing the full dataset [*F(8)=2.839, p=0.0083*]. Statistically significant differences were also detected when seperately analysing rugby playing participants [*F(4)=3.798, p=0.0087*]. However, there were no significant differences between individuals within the control, non-rugby playing, participants [*F(3)=2.536, p=0.083*]. This suggests that RT variability is greater in rugby players than non rugby playing participants.

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in RT variability over time in rugby playing participants. There were no outliers and the data was found to be normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. Mean RT variability increased between Week 1 (14.12 ± 8.803), Week 2 (19.55 ± 5.51), Week 3 (21.48 ± 10.84) and Week 4 (43.22 ± 41.63) but then decreased in Week 5 (30.08 ± 18.36) and week 6 (15.64 ± 3.82). However, there were no statistically significant changes in RT variability over time [$F (5, 15) = 1.134, p = 0.385$].

In summary, only Simultaneous Amplitude Discrimination out of four raw output dependent variables (Reaction time, Sequential amplitude discrimination, simultaneous amplitude discrimination and Reaction Time variability) showed statistically significant differences over time.

4.6 Practical Utilisation of the Brain Gauge Technology

Normalised multi-parametric data obtained from the Brain Gauge system is presented graphically in Figures 4 and 5 for participants C and E. For each participant, measures of mental acuity (Accuracy, Focus, Speed and Fatigue) are presented. The lower number (closer to zero) and colour (red) indicates a deterioration of performance for that particular measure of brain health. In contrast, a higher score (closer to 100) indicates a healthier score. Using radar plots to visualize the data allows a rapid and objective means of measuring physiological differences between and within individuals. This is shown below for two of the participants and illustrates differences between participants C and E for any given time point. Furthermore, measurements for each individual over the six-week time period can be visualized and compared.

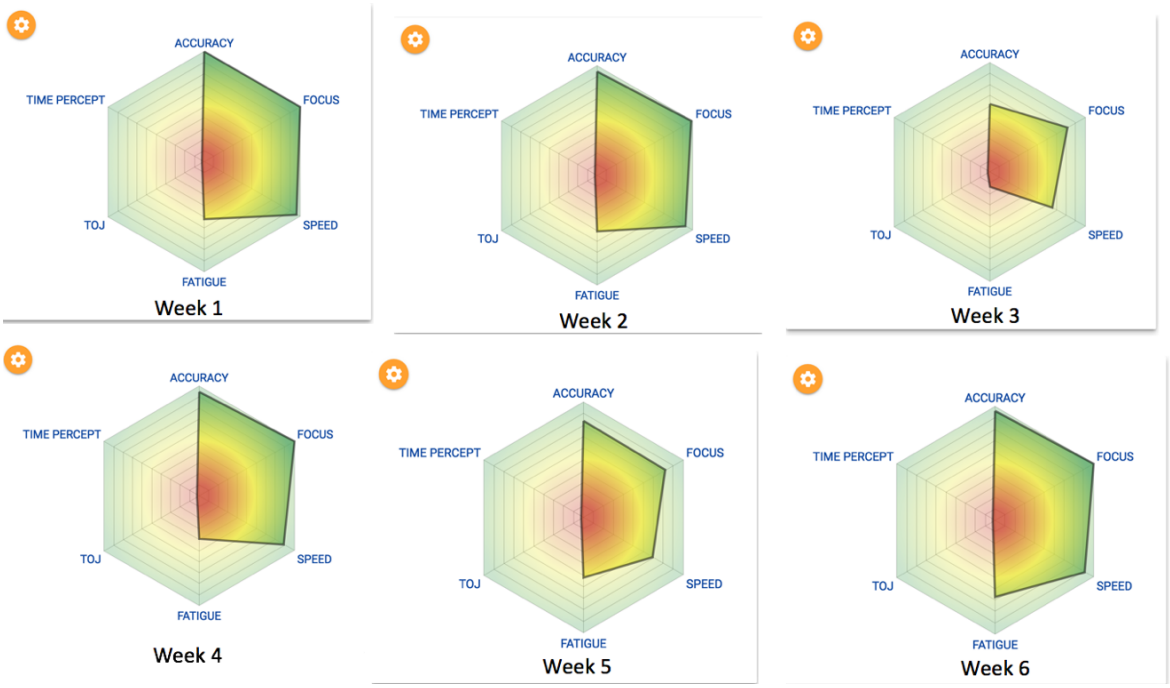

Figure 4 Radar Plots (showing visual representation of variation in 4 measures of mental acuity across a 6 week period for participant C.

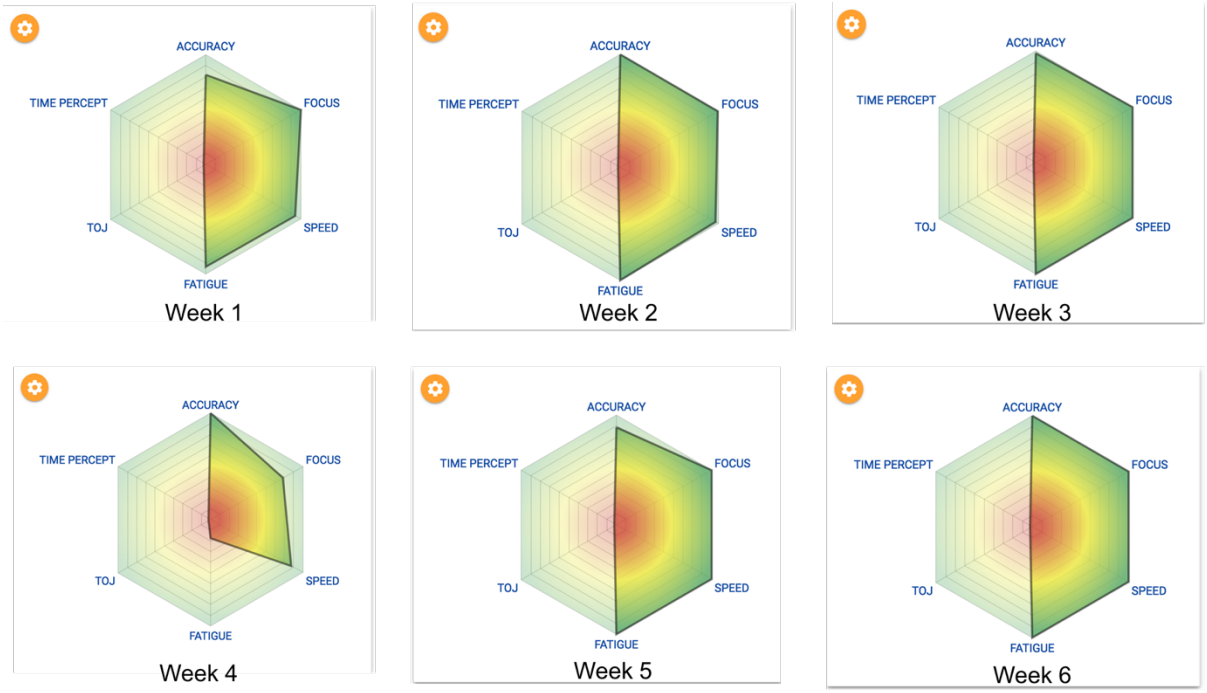

Figure 5 Radar Plots (showing visual representation of variation in 4 measures of mental acuity across 6 weeks for participant E.

Radar plots for the five participants (A,B,C,D,E) together with four controls (A,B,C,D) are shown in Appendix 4 for four measures of mental acuity collected over a six-week period. Visualisation of the data in the form of spider plots reinforces the results obtained from the statistical analysis of the Brain Gauge variables where differences between individuals were more prominent than changes detected over time.

This can be seen in Figure 4 where participant C shows dramatic changes in accuracy, focus and speed in Week 3, followed by subsequent improvement in weeks 5 and 6. The overall profile pattern for participant C differs from participant E (Figures 4 and Figure 5). Interestingly, for both participants mental acuity appears to deteriorate in the intermediate weeks (3 & 4), followed by subsequent improvements in week five and six.

4.7 Rivermead Symptom Questionnaire Pearson's Correlations

Data from pairwise Pearson correlations of average symptom scores (self-reported Rivermead Questionnaire) is displayed in Table 2 in the form of a heat map. Positive correlations (0->1) are denoted in red, while negative correlations (-1->0) are denoted in blue. The intensity of the colour increases as the strength of the association increases. Scrutiny of Table 2 allows for potential correlations between symptoms to be identified e.g. fatigue and nausea correlate highly together (0.98), as well as sleep disturbance and headaches (0.98). In contrast, irritability and light sensitivity show little or no association (-0.01). It should be noted that blurred vision or light sensitivity show consistent negative correlations with all other symptoms (excluding themselves).

Table 2 shows a heatmap of a pairwise Pearson's correlations between average symptom scores across rugby playing individuals

	Headaches	Nausea	Sleep disturbance	Fatigue, being more tired easily	Irritable, angered easily	Feeling depressed or tearful	Feeling frustrated or impatient	Forgetfulness or poor memory	Poor concentration	Taking longer to think	Blurred vision	Light sensitivity	Restlessness
Headaches	1.00	0.80	0.98	0.69	0.84	0.98	0.93	0.80	0.24	0.73	-0.69	-0.25	0.85
Nausea	0.80	1.00	0.76	0.98	0.36	0.87	0.58	1.00	0.73	0.96	-0.33	-0.57	0.40
Sleep disturbance	0.98	0.76	1.00	0.63	0.81	0.98	0.97	0.76	0.28	0.63	-0.56	-0.07	0.90
Fatigue, being more tired easily	0.69	0.98	0.63	1.00	0.21	0.77	0.43	0.98	0.79	0.97	-0.25	-0.66	0.24
Irritable, angered easily	0.84	0.36	0.81	0.21	1.00	0.72	0.88	0.36	-0.32	0.33	-0.86	-0.01	0.90
Feeling depressed or tearful	0.98	0.87	0.98	0.77	0.72	1.00	0.90	0.87	0.43	0.76	-0.52	-0.22	0.80
Feeling frustrated or impatient	0.93	0.58	0.97	0.43	0.88	0.90	1.00	0.58	0.08	0.43	-0.58	0.12	0.98
Forgetfulness or poor memory	0.80	1.00	0.76	0.98	0.36	0.87	0.58	1.00	0.73	0.96	-0.33	-0.57	0.40
Poor concentration	0.24	0.73	0.28	0.79	-0.32	0.43	0.08	0.73	1.00	0.61	0.40	-0.30	-0.08
Taking longer to think	0.73	0.96	0.63	0.97	0.33	0.76	0.43	0.96	0.61	1.00	-0.46	-0.78	0.25
Blurred vision	-0.69	-0.33	-0.56	-0.25	-0.86	-0.52	-0.58	-0.33	0.40	-0.46	1.00	0.43	-0.57
Light sensitivity	-0.25	-0.57	-0.07	-0.66	-0.01	-0.22	0.12	-0.57	-0.30	-0.78	0.43	1.00	0.28
Restlessness	0.85	0.40	0.90	0.24	0.90	0.80	0.98	0.40	-0.08	0.25	-0.57	0.28	1.00

4.8 Relationship between Rivermead Symptom Score and average Brain Gauge data

Data from pairwise Pearson's correlations between average symptom score (from Self-reported Rivermead Questionnaire) and Reaction Time, Reaction Time Variability, Sequential Amplitude Discrimination and Simultaneous Discrimination obtained from the Brain Gauge Somatosensory device are shown in Table 3 and visualised in Figure 6. Of particular note is the positive correlation between reaction time and the following symptoms: nausea (0.95), fatigue (0.90), feeling depressed (0.93) and poor memory (0.95). This positive correlation and trend is also observed for reaction time variability. Light sensitivity (-0.28) and Blurred vision (-0.23) were found to be weakly and negatively correlated with Reaction Time. The other Brain Gauge metrics, Sequential and Simultaneous Amplitude Discrimination were found to be positively correlated with Restlessness (0.81 and 0.85 respectively).These correlations can be easily visualized in the heat map (Figure 6 where the darkness of the square represents an increasing negative correlation between two factors, while lightness indicates an increasing positive correlation between two factors. This can make it difficult to identify intermediate correlation values (those around 0). Therefore, more detailed conclusions can be drawn from the data. presented in Table 3. In addition, the correlation does not imply any causative relationship between the symptom questionnaire and the Brain Gauge data but highlights important trends and associations.

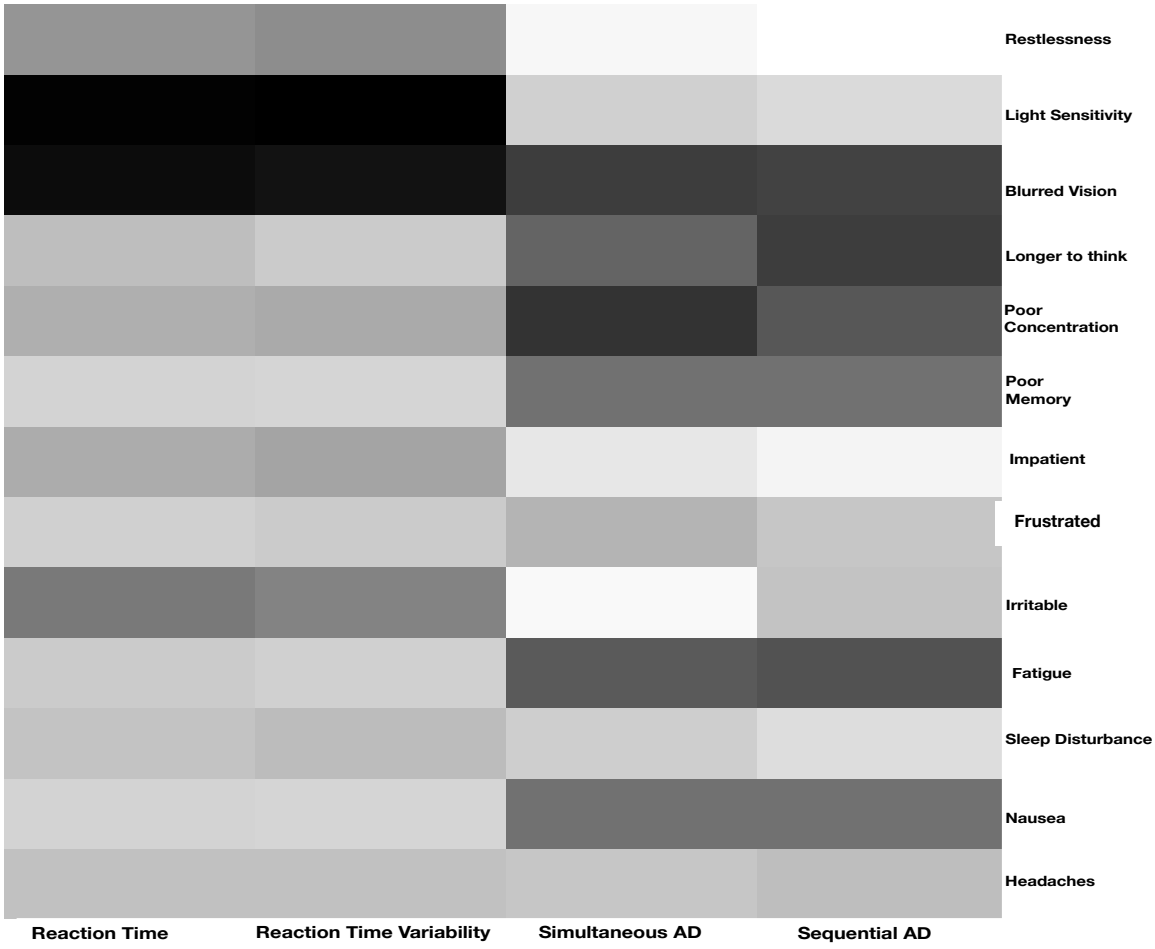

Figure 6 shows a Heatmap of a Pairwise correlational analysis between average Rivermead Symptom Score and Average Brain Gauge score (Reaction Time, Reaction Time Variability, Simultaneous Amplitude Discrimination and Sequential Amplitude Discrimination).

Table 3 Pairwise correlation matrix between average symptom score of Rivermead Symptom Questionnaire and average scores for; Reaction Time, Reaction Time Variability, Sequential Amplitude Discrimination and Simultaneous Amplitude Discrimination.

	Headaches	Nausea	Sleep disturbance	Fatigue	Irritable,	Feeling depressed	Feeling frustrated	Poor memory	Poor concentration	Longer to think	Blurred vision	Light sensitivity	Restlessness
Reaction time (RT)	0.84	0.95	0.86	0.90	0.42	0.93	0.72	0.95	0.73	0.82	-0.23	-0.28	0.58
RT variability	0.85	0.99	0.82	0.96	0.43	0.92	0.66	0.99	0.70	0.93	-0.35	-0.48	0.50
Sequential AD	0.45	-0.18	0.50	-0.34	0.82	0.32	0.69	-0.18	-0.63	-0.26	-0.55	0.52	0.81
Simultaneous Amplitude Discrimination	0.53	0.17	0.69	0.01	0.56	0.57	0.80	0.17	0.04	-0.09	-0.06	0.68	0.85

5 Discussion

5.1 Context and significance of the study

This study has addressed an important problem that is of growing importance in contact sport, namely the incidence and consequences of Sports Related Concussion (SRC) (Marshall and Spencer, 2001; Pellman *et al.*, 2003; McCrea *et al.*, 2004; McCrory *et al.*, 2013). It has been estimated that the incidence of concussion or mild traumatic brain injury ranges from 1.6 million to 3.8 million affected people per annum in the USA, with one in five individuals being younger than 19 and treated for SRC (Maegele, 2018). While concussion awareness has improved over the past decade (Giza, Prins and Hovda, 2017), it is difficult to diagnose and treat because of the absence of established and agreed criteria that accurately define SRC (McCrory et al 2017). The incidence of SRC has received widespread acknowledgement, most notably in the media (Armytage, 2018; Schofield, 2018) since the reporting of post-mortem examination of brains from deceased American Football players that showed a high proportion of chronic traumatic encephalopathy (CTE) (Mez *et al.*, 2017). Furthermore there has been one report of CTE in a deceased rugby player (Stewart *et al.*, 2016). This has placed greater pressure on sporting bodies to review protocols in the professional levels of rugby union. Despite this focus in the professional levels of sport, the majority of SRC actually occurs at the amateur level. Without adequate medical cover and training relative to their professional counterparts, adolescent and amateur athletes are at an elevated risk of having SRC diagnosis delayed or missed entirely. This has in some cases called for contact sports to be banned in younger age groups (Kirkwood *et al.*, 2015). Despite the ‘public outcry’ there has been little appetite to address SRC in a systematic manner to provide the objective evidence base to support the safety and welfare of players at the amateur and adolescent levels of the game.

Diagnosis and monitoring of SRC is hugely challenging. Recovery from SRC may take days or weeks, with individuals often experiencing dizziness, headaches, double vision, memory problems, irritability and depression (McCrory *et al.*, 2017). The wide variability in severity and type of symptoms experienced following a concussion makes diagnosis and return to play decisions very difficult.

Premature return to play following a concussion without adequate recovery time, can lead to potentially serious consequences including death (Lovell *et al.*, 2003). Hence there is an urgent need to develop and test new methods of objectively detecting and monitoring the neuro-functional effects of concussion in contact sports such as rugby. Traditional methods based on established neurological and radiological procedures are highly efficient at detecting serious brain injuries and fractures of the skull, but are less effective at detecting defective neurocognitive function associated with SRC (Tommerdahl *et al.*, 2016; Corticalmetrics, 2018). Therefore, clinicians have to rely on subjective and observational clinical judgement to diagnose, monitor and determine a player's readiness to return to play. This has potential serious consequences for players who are allowed to resume playing prematurely. These factors have prompted the development of new disruptive technologies to measure brain health, concussion and other neurological disorders. (O'Connor *et al.*, 2017). In this study the Brain Gauge (Corticalmetrics, 2018) somatosensory system was used for the first time to monitor and measure aspects of brain health in a group of five rugby players over the course of a single playing season.

5.2 The Brain Gauge Technology and its Applicability to Sports Related Concussion (SRC)

The Brain Gauge is a novel and innovative brain health assessment system that takes advantage of the well-documented relationship between the sensory nerves in the fingers and the projection of those nerves to corresponding regions in the brain (D. King, Hume and Tommerdahl, 2018). It is a mouse sized device that uses fingertip vibration patterns to probe cortical function and thereby determine and identify specific aspects of compromised neural function.

It's development is based on over five decades of basic research in neurobiology and technology development resulting in a series of hands on battery neurocognitive tests that has been scientifically validated to measure the effects of concussion and other neurological disorders (Tommerdahl *et al.*, 2018).

The method has similarities to the way eye testing is conducted at an optician: as you answer the questions correctly, the successive questions become more difficult in order to approach your limits of detection. The results are recorded in a series of metrics that relate to cognitive function and include: focus, fatigue, reaction time and timing perception. The combination of these metrics represents an individual's overall ability to process information.

The Brain Gauge has a number of distinct advantages to measure brain health. These include real time measurement of brain function which is 'biologically' based using the somatosensory system (D. A. King, Hume and Tommerdahl, 2018; Tommerdahl *et al.*, 2018). In addition, the tests originate from long-standing neuroscience research. The objective data outputs allow for rigorous statistical significance testing which can give probability scores to be assigned to the findings. Furthermore, the Brain Gauge offers several advantages for assessing concussed individuals. As shown by King et al (2018), the approach does not depend on the availability of base line data which enables participants to be tested and monitored without any prior knowledge or assumptions regarding concussion.

5.3 Novel Aspects of the Study

Within the limits of sample size (n=5), this research has demonstrated the ability to successfully monitor measures of mental acuity across a period of 6 games using the Brain Gauge somatosensory device. One of the most important clinically relevant finding from this study is that significant differences were detected between individuals for 3 of the 4 (Reaction Time, Simultaneous Amplitude Discrimination and Reaction Time Variability) measures of mental acuity measured by the Brain Gauge somatosensory device.

This significant finding suggests that the Brain Gauge is able to detect variation between individuals across multiple measures linked with brain health. This has major implications for the widespread utility of the Brain Gauge to accurately assess the brain health of individuals.

This finding supports the initial data produced by Tommerdahl (2010) and King (2018), who demonstrated that the Brain Gauge was sensitive and objective in monitoring changes in brain health of a single individual case study recovering from concussion. With reference to the reaction time metric, the group mean of 240 in milliseconds (ms) appears to exceed the normal range (150-200 milliseconds) considered to be normal. This has implications for the characterisation of what is considered 'normal' for University rugby players, where reaction time has not been quantified amongst University rugby players. Recently published research identified that 18-22 year old military males exhibited a mean reaction time of 220 milliseconds (ms) ±3 ms (Cole *et al.*, 2018). However, the sample size within our cohort of players is too small to draw broader conclusions.

Reaction Time variability (RT variability) has been shown to be related closely to attentional function and frontal lobe function (Tamm *et al.*, 2012; Cole *et al.*, 2018; D. King, Hume and Tommerdahl, 2018). High RT variability score is associated with migraine, non-headache chronic pain, and traumatic damage to the cerebellum. Therefore, RT variability is an important parameter when considering the brain function of individuals. Both the mean RT variability of experimental and control participants were within the range of 15-30ms and no significant differences were detected between experimental and control participants. In addition, there were no significant changes in RT variability over time ($p>0.05$). This suggests an absence of an aggregation effect on measures of mental acuity over time. Studies comparing neurological status and reaction time performance have been conducted over the past century and date back to 1868. It is well established that both reaction time and reaction time variability can be compromised with impairment in neurological function (Donders, 1969; MacDonald, Nyberg and Bäckman, 2006; Tamm *et al.*, 2012).

More recently, reaction time tasks have been shown to affected when suffering from concussion, together with reaction time variability which has shown to be correlated with attention and focus (Eckner et al. 2015; Ruesch 1944).

Due to the relatively short nature of the study (6 weeks) we are unable to ascertain whether these reaction times are within the 'normal' range for these participants or whether these could be due to impairment in neurological function attributed to

participation in rugby union. This clearly demonstrates the need for more base line data on brain health for University rugby players and other contact sports.

The normative ranges for healthy individuals described from previous studies for both Simultaneous Amplitude Discrimination and Sequential Amplitude Discrimination are 20 and 70 microns (Francisco *et al.*, 2008; Zhang *et al.*, 2008). The group mean for Sequential Amplitude Discrimination were all within this normative ranges of 20-70 microns. This suggests that the sample of rugby players used in the study fall within a normative range considered to be 'healthy', unlike Reaction Time, whereby all experimental participants except one were outside the normative range. Comparison of the Sequential versus Simultaneous Amplitude Discrimination (AD) tasks provides an unique insight into the process of lateral inhibition as described by (Tommerdahl, Favorov and Whitsel, 2010). The 'Accuracy' metric computed by the Brain Gauge is calculated using both Sequential and Simultaneous AD tasks and the 'Plasticity' metric is calculated from the relationship between the two. In healthy participants the Simultaneous AD score has been demonstrated to be approximately equal to the Sequential AD score (Francisco *et al.*, 2008). The important measure is the ratio of the Simultaneous AD score to the Sequential AD score: the poorer the score for the Simultaneous task relative to the Sequential task, the lower the score for plasticity. The Simultaneous Amplitude Discrimination should not be more than 50% higher than that of Sequential Amplitude Discrimination. Poor scoring for Simultaneous AD has been found to be common in participants exhibiting hypersensitivity e.g. migraines (Nguyen *et al.*, 2013). Based on the data from the current study, there appears to be considerable variation between individuals for percentage differences between Simultaneous Amplitude Discrimination and Sequential Amplitude Discrimination (Figure 7), with some individuals (participant C and A) displaying large differences. However, none of the individuals had a percentage difference greater than 50% suggesting that the participants could considered within normal functioning for the plasticity index.

A second finding with clinical importance was the absence of a statistically significant effect of time on measures of mental acuity (RT, RT variability, Sequential Amplitude Discrimination) measured over the six-week testing period.

This suggests that within this experiment, measures of mental acuity are not changing over time and the Brain Gauge produces robust results over the testing period.

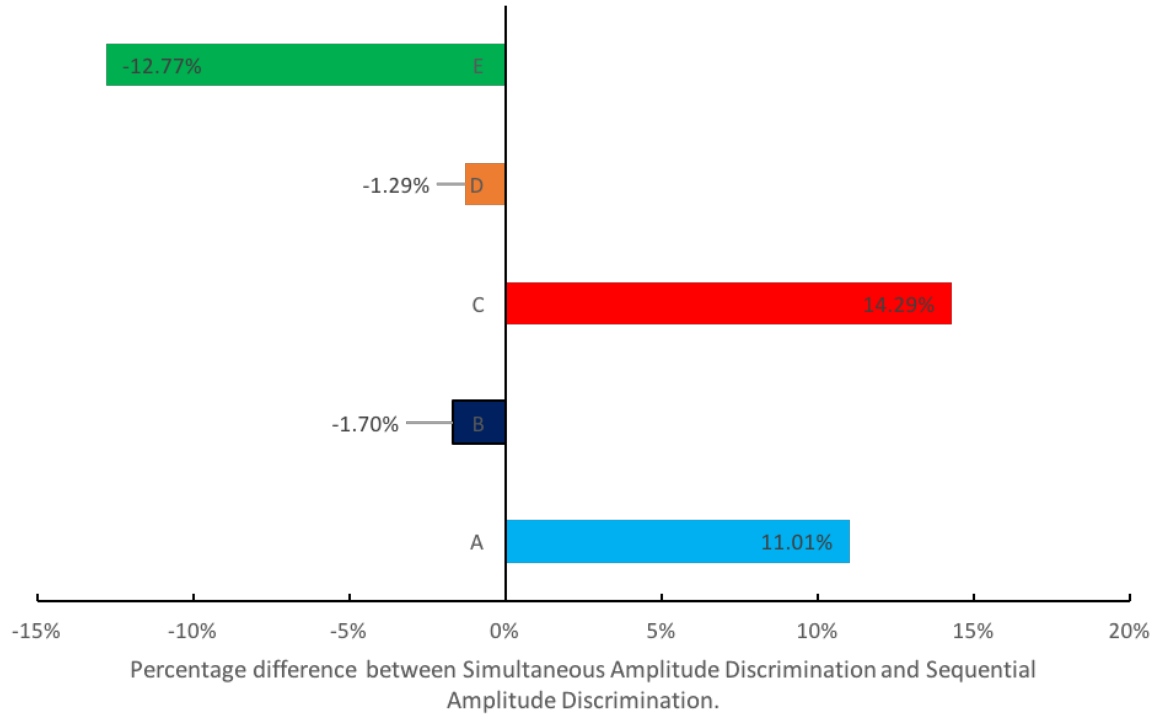

Figure 7 Averaged Percentage difference between Simultaneous Amplitude Discrimination and Sequential Amplitude Discrimination expressed as percentage. (% Across all individuals (A,B,C,D)

5.4 Brain Gauge Symptom Correlation Analysis

The Rivermead Post Concussion Questionnaire has been used extensively in monitoring and tracking recovery of patients from SRC (Eyres *et al.*, 2005; Herrmann *et al.*, 2009; de Guise *et al.*, 2016). Furthermore, currently multi stage return to play protocols state that a participant must be symptom free before progressing to the next stage and ultimately before returning to play (McGrath, 2010; Hollis *et al.*, 2012; Johnson, 2012). However, studies monitoring cerebral blood flow have also shown that although players may be symptom free, physiologically the brain has not fully recovered (Meier *et al.*, 2015; Churchill *et al.*, 2017). Therefore closely analysing the relationship between brain function and symptom severity is an important step in validating the accuracy and reliability of symptoms based questionnaire such as the Rivermead or Sports Concussion Assessment Tool (McCrory *et al.*, 2017).

Results from pairwise correlations between average Brain Gauge scores and average symptom questionnaire score showed ‘Feeling depressed (0.93)’ and ‘Poor memory (0.95)’, were both strongly positively correlated with increased Reaction Time and Reaction Time variability. This supports earlier conclusions that reaction time tasks are affected within SRC patients and are shown to be correlated with attention and task focus (Eckner et al. 2015; Ruesch 1944). Contrastingly Light sensitivity (-0.28) and Blurred vision (-0.23) were found to be consistently weakly and negatively correlated with Reaction Time scores. Of more interest, Sequential and Simultaneous Amplitude Discrimination were found to correlate strongly with Restlessness (0.81 and 0.85 respectively). This corroborates with research demonstrating simultaneous AD is compromised in populations with hypersensitivity which could include restlessness (Nguyen *et al.*, 2013). These initial results suggest that there could be trends and patterns between symptoms and specific brain function. With further research examining larger data sets a more robust relationship between Brain Gauge score and symptom score could be established.

In addition, pairwise correlation analysis was undertaken among the average symptom scores themselves. The aim of this was to explore if any symptoms correlated well with any other types of symptoms. Fatigue and Nausea showed

strong positive correlations (0.98) as well as sleep disturbance and headaches (0.98). Contrastingly, irritability and light sensitivity did not show evidence of association (-0.01).

To date most research on SRC has been observational and has not benefited from the deployment of novel technology developed from laboratory-based neuroscience research. Although preliminary, this study has attempted to address this shortcoming through the deployment of Brain Gauge technology to determine brain health in University rugby players. Concussion represents a highly complex injury that will require further research to support clinical management and the evidence base to comprehensively guide future return to play guidelines for rugby and other contact sports.

5.5 Limitations of the study

The current study was based on a relatively small sample size (n=5), therefore the ability to detect small differences or changes in measures of mental acuity is limited. In addition, the study only focused on the last six games of the season rather than a full playing season. This was due to experimental time constraints. However, the six games did occur after a period of approximately four weeks of 'washout' period when the students would not have played in any official University rugby union games. Furthermore, the control group used in this study was not balanced, the control group included inactive rugby players who were currently not playing rugby together with non-rugby players. The presence of additional extraneous variables such as short-term illness, alcohol intake, sleep, academic stress or other commitments may also have confounded the results. In addition, participants were asked to describe their concussion history via self-reporting over the past 24 months which is highly subjective. Although all testing was completed in a constant environment (quiet room) and at regular time intervals it was difficult to control prior behaviour of participants in advance of testing.

5.6 Future Work opportunities

This study has provided an initial step towards establishing methods for collating brain health data amongst University rugby players. The study also demonstrated the utility and practical application of the Brain Gauge to rugby union.

The application of this technology could be extended to a range of other sports including Soccer, Hockey and Boxing. Within the context of the current study, further work could include the testing and incorporation of data from a full squad of players tested across the full playing season.

A comprehensive suite of data including; training regime, diet, sleep, alcohol intake and measures of stress would be collated and analysed alongside quantitative data from the Brain Gauge. This would enable a more rigorous and statistically robust analysis of the relationship between various external quantitative parameters (e.g. training regime, diet, sleep, alcohol intake and measures of stress) and brain health with a goal of establishing, at an individual level, changes in brain function across a full playing season.

Other opportunities for future work would include extending the approach described by King et al (2018), who investigated recovery from concussion for a single individual who suffered a bicycle accident. In the current study, no concussions amongst the cohort of players were detected. The principles and foundations established through this preliminary study could be extended to investigate recovery from SRC with appropriate ethical agreement and support.

More broadly, the application for somatosensory devices such as the Brain Gauge has broad applicability beyond SRC. Indeed, the Brain Gauge was originally developed from several decades of neurophysiological research and provides a robust, non-invasive, real time method to measure brain health. Although not yet fully explored in the allied health profession, clear opportunities exist for the exploitation of this technology for the detection, treatment and monitoring of patient recovery in the fields of other neurological disorders such as stroke, Parkinson’s and mental health, substance abuse and ageing.

6 Conclusions

This study has demonstrated that the Brain Gauge somatosensory technology is capable of detecting significant differences between rugby players across a broad range of brain health measures. These include Reaction Time, Reaction Time Variability and Simultaneous Amplitude Discrimination, which collectively provide real time measures of overall brain health. Although significant differences were detected between individuals, with the exception of Simultaneous Amplitude Discrimination, there were no statistically significant changes in measures of brain health over time. This demonstrates the Brain Gauge technology to be robust and capable of providing reliable data.

Through the inclusion of the Rivermead Symptom Questionnaire, it was possible to relate individual symptoms with measures of brain health determined by the Brain Gauge technology.

For example, a consistent positive correlation was detected between individuals exhibiting restlessness and increased Simultaneous Amplitude Discrimination and Sequential Amplitude Discrimination scores. A second example is Reaction Time, which is strongly positively correlated with a suite of related symptoms that include Nausea, Fatigue, Feeling Depressed and Poor Memory. In other words, slower Reaction Time is associated with the above symptoms.

Overall this study has demonstrated the potential of this approach to be deployed by physiotherapists and medical staff to help detect and monitor the recovery of players and their safe return to play following SRC. In addition this approach opens up the potential of remote monitoring of recovery from Sports Related Concussion through the use of Brain Gauge technologies for a range of contact sports.

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8 Appendices

8.1 Appendix 1: Description of six measures calculated by the Brain Gauge

Measure Category	Specific Statistic	Statistic Description
Cortical Metric Somatosensory assessment	Speed	Computed from reaction time (RT) and variability (RTVar) on the RT tests. Speed is dependent on white matter integrity and frontal-parietal pathways. Disruption of white matter integrity occurs with a number of conditions such as traumatic insult (TBI), MS and some neurodegenerative conditions. High variability has been linked to micro- lesions in the white matter. When performance degrades between the first and second reaction time tests, the Fatigue score will be poor (low value).
	Accuracy	Reliant on functional integrity in the parietal lobe and comprises the averaged Amplitude Discrimination (AD) scores (AD sequential (ADseq) and AD simultaneous (ADsimult)). This metric reflects one's ability to accurately determine which of two stimuli is larger in size (amplitude). Accuracy is reliant on functional integrity in the parietal lobe. Lower numbers are better but both AD values should be similar. Systemic hyperactivity in the cerebral cortex, or an imbalance in excitation/inhibition, can cause a large divergence between the ADseq and ADsimult values. When ADsimult is much greater than ADseq, there are likely problems with lower than normal inhibition or greater than normal activity (hyper-responsively). This can cause a low Plasticity score, which is often observed in chronic pain participant (e.g., migraine), some participant with neurodegenerative problems and participant with traumatic insult, particularly to the parietal lobe. Two stimuli are delivered in each of the AD tests: the stimuli are given one after the other in ADseq while both are delivered at the same time in ADsimult.
	Plasticity	Measure of how well your brain is integrating, processing, and adapting to information from its external environment. States of hyper-excitation (such as can be caused by low GABA levels) lead to poor plasticity scores. Plasticity is a computed metric and a weighted average of lateral inhibition, adaptation and temporal- intensity integration metrics. A comparison of ADseq with ADsimult yields information about lateral inhibition: how well the brain discriminates between two points. ADsimult should not be more than ~50% higher than ADseq. Low GABA can be responsible for low lateral inhibition. A measure of the impact that single site adaptation (SSA) has on amplitude discrimination yields an adaptation metric. The delivered adapting stimulus should be illusory and cause SSA to be ~30% worse than the ADsimult score. A measure of timing perception in the presence of intensity confounds yields a temporal-intensity integration score. Timing perception with confound (DDc) should be ~30% worse than timing perception without the illusion (DD).
	Fatigue	Fatigue is computed from the first and last reaction time tests. If performance declines between the first and second reaction time tests, the Fatigue score will be poor (low value).
	Focus	Focus is computed from reaction time variability. It measures the ability to attend to a task.
	Cortical Metric	The CorticalMetric is an overall representation of brain health. It takes the information collected from every available test and computes an "at a glance" view of total brain health.
Symptom monitoring Questionnaire	Rivermead symptom questionnaire	The Rivermead Questionnaire, can be given to someone following a concussion to monitor their symptoms. The three symptoms at the start relate to early symptoms and post concussion syndrome. The remaining thirteen are associated with late symptoms.

8.2 Appendix 2: Showing individual results for all participants (A,B,C,D,E) and Controls (A,B,C,D)

Participant A		Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Measure	Range	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff
Reaction Time A (ms)	150-200 ms	266.40	66.40	317.60	117.60	329.00	129.00	332.00	132.00	351.00	151.00	319.40	119.40
Reaction Time B (ms)	150-200 ms	326.20	126.20	327.20	127.20	306.40	106.40	311.60	116.60	381.40	181.40	311.80	111.80
Reaction Time variability A	0-20	26.10	6.10	27.90	07.90	27.00	7.00	16.20	-3.80	39.50	19.50	14.40	-5.60
Reaction Time variability B	0-20	27.50	7.50	27.30	07.30	43.90	23.90	45.6	25.60	16.90	-3.10	25.40	5.40
Sequential Amplitude Discrimination (microns)	20-70 microns	21.00	-49.00	88.00	18.00	11.00	-59.00	64.00	-6.00	52.00	-18.00	17.00	-53.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	96.00	26.00	72.00	02.00	57.00	-13.00	36.00	-34.00	49.00	-21.00	41.00	-29.00

Participant C		Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Measure	Range	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff
Reaction Time A (ms)	150-200 ms	196.80	-3.20	195.60	-4.40	223.20	23.20	201.80	1.80	233.60	33.60	195.80	-4.20
Reaction Time B (ms)	150-200 ms	180.40	-19.60	196.80	-3.20	257.80	57.80	212.60	12.60	230.60	30.60	204.80	4.80
Reaction Time variability A	0-20	6.00	-14.00	13.50	-6.50	8.40	-11.60	10.10	-9.90	17.70	-2.30	9.70	-10.30
Reaction Time variability B	0-20	9.40	-10.60	20.80	0.80	34.90	14.90	17.10	-2.90	33.90	13.90	11.80	-8.20
Sequential Amplitude Discrimination (microns)	20-70 microns	13.00	-57.00	13.00	-57.00	8.40	-61.60	25.00	-45.00	76.00	6.00	49.00	-21.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	28.00	-42.00	52.00	-18.00	34.90	-35.10	52.00	-18.00	28.00	-42.00	15.00	-55.00

Participant B		Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Measure	Range	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff
Reaction Time A (ms)	150-200 ms	250.40	50.40	269.60	69.60	287.70	-87.70	263.20	63.20	*	*	*	*
Reaction Time B (ms)	150-200 ms	258.80	58.80	269.60	69.60	286.00	-86.00	269.40	69.40	*	*	*	*
Reaction Time variability A	0-20	36.50	16.50	5.70	-14.30	40.00	-20.00	4.20	-15.80	*	*	*	*
Reaction Time variability B	0-20	22.50	2.50	8.90	-11.10	18.20	1.80	23.80	3.80	*	*	*	*
Sequential Amplitude Discrimination (microns)	20-70 microns	72.00	2.00	32.00	-38.00	40.00	30.00	37.00	-33.00	*	*	*	*
Simultaneous Amplitude Discrimination (microns)	20-70 microns	88.00	18.00	37.00	-33.00	16.00	54.00	44.00	-26.00	*	*	*	*

Participant D		Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Measure	Range	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff
Reaction Time A (ms)	150-200 ms	235.80	35.80	239.20	39.20	217.80	17.80	228.20	28.20	215.40	15.40	211.00	11.00
Reaction Time B (ms)	150-200 ms	207.80	7.80	196.60	-3.40	229.20	29.20	227.20	27.20	246.40	46.40	211.80	11.80
Reaction Time variability A	0-20	10.20	-9.80	19.00	-1.00	24.20	4.20	22.10	2.10	92.00	72.00	15.20	-4.80
Reaction Time variability B	0-20	16.50	-3.50	11.40	-8.60	15.30	-4.70	25.20	5.20	18.40	-1.60	15.00	-5.00
Sequential Amplitude Discrimination (microns)	20-70 microns	37.00	-33.00	64.00	-6.00	88.00	18.00	36.00	-34.00	92.00	22.00	60.00	-10.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	52.00	-18.00	84.00	14.00	88.00	18.00	108.00	38.00	84.00	14.00	68.00	-2.00

Participant E		Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
Measure	Range	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff	Actual	Diff
Reaction Time A (ms)	150-200 ms	190.60	-9.40	193.20	-6.80	158.40	-41.60	165.50	-34.50	160.40	-39.60	170.80	-29.20
Reaction Time B (ms)	150-200 ms	195.80	-4.20	186.80	-13.20	165.00	-35.00	188.60	-11.40	162.80	-37.20	164.60	-35.40
Reaction Time variability A	0-20	12.50	-7.50	20.50	0.50	7.00	-13.00	20.90	0.90	11.20	-8.80	13.80	-6.20
Reaction Time variability B	0-20	4.80	-15.20	16.00	-4.00	11.10	-8.90	188.60	168.60	11.10	-8.90	19.80	-0.20
Sequential Amplitude Discrimination (microns)	20-70 microns	80.00	10.00	17.00	-53.00	44.00	-26.00	13.00	-57.00	64.00	-6.00	28.00	-42.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	28.00	-42.00	19.00	-51.00	13.00	-57.00	33.00	-37.00	5.00	-65.00	21.00	-49.00

Control A		Week 1		Week 2	
Measure	**Range**	**Actual**	**Diff**	**Actual**	**Diff**
Reaction Time A (ms)	150-200 ms	281.80	81.80	259.80	59.80
Reaction Time B (ms)	150-200 ams	208.20	8.20	266.80	66.80
Reaction Time variability A	0-20	41.70	21.70	24.50	4.50
Reaction Time variability B	0-20	8.90	-11.10	21.90	1.90
Sequential Amplitude Discrimination (microns)	20-70 microns	33.00	-37.00	21.00	-49.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	84.00	14.00	56.00	-14.00

Control B		Week 1		Week 2	
Measure	**Range**	**Actual**	**Diff**	**Actual**	**Diff**
Reaction Time A (ms)	150-200 ms	219.80	19.80	191.40	-8.60
Reaction Time B (ms)	150-200 ms	216.40	16.40	200.20	0.20
Reaction Time variability A	0-20	13.70	-6.30	19.40	-0.60
Reaction Time variability B	0-20	15.10	-4.90	22.60	2.60
Sequential Amplitude Discrimination (microns)	20-70 microns	36.00	-34.00	45.00	-25.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	56.00	-14.00	76.00	6.00

Control C		Week 1		Week 2	
Measure	**Range**	**Actual**	**Diff**	**Actual**	**Diff**
Reaction Time A	150-200 ms	315.00	115.00	264.00	64.00
Reaction Time B	150-200 ms	281.80	81.80	233.60	33.60
Reaction Time variability A	0-20	24.40	4.40	9.00	-11.00
Reaction Time variability B	0-20	18.60	-1.40	11.30	-8.70
Sequential Amplitude Discrimination (microns)	20-70 microns	11	-59.00	49.00	-21.00
Simultaneous Amplitude Discrimination (microns)	20-70 microns	33	-37.00	11.00	-59.00

Control D		Week 1		Week 2	
Measure	**Range**	**Actual**	**Diff**	**Actual**	**Diff**
Reaction Time A	150-200 ms	175.8	-24.2	170.6	-29.4
Reaction Time B	150-200 ms	180.8	-19.2	171.6	-28.4
Reaction Time variability A	0-20	4.7	-15.3	4.2	-15.8
Reaction Time variability B	0-20	15.1	-4.9	11.6	-8.4
Sequential Amplitude Discrimination (microns)	20-70 microns	56	-14	13	-57
Simultaneous Amplitude Discrimination (microns)	20-70 microns	112	42	64	-6

8.3 Appendix 3: Rivermead Questionnaire used to measure symptoms.

The Rivermead Post-Concussion Symptoms Questionnaire*

After a head injury or accident some people experience symptoms which can cause worry or nuisance. We would like to know if you now suffer from any of the symptoms given below. As many of these symptoms occur normally, we would like you to compare yourself now with before the accident. For each one, please circle the number closest to your answer.

0 = Not experienced at all
1 = No more of a problem
2 = A mild problem
3 = A moderate problem
4 = A severe problem

Compared with before the accident, do you now (i.e., over the last 24 hours) suffer from:

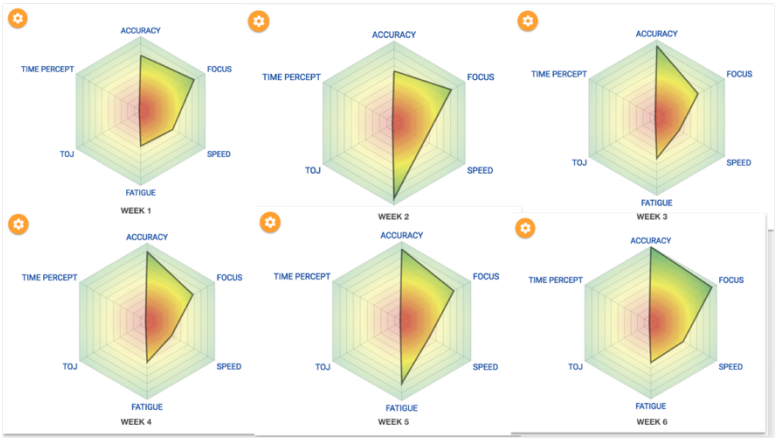
Headaches	0	1	2	3	4
Feelings of Dizziness	0	1	2	3	4
Nausea and/or Vomiting	0	1	2	3	4
Noise Sensitivity, easily upset by loud noise	0	1	2	3	4
Sleep Disturbance	0	1	2	3	4
Fatigue, tiring more easily	0	1	2	3	4
Being Irritable, easily angered	0	1	2	3	4
Feeling Depressed or Tearful	0	1	2	3	4
Feeling Frustrated or Impatient	0	1	2	3	4
Forgetfulness, poor memory	0	1	2	3	4
Poor Concentration	0	1	2	3	4
Taking Longer to Think	0	1	2	3	4
Blurred Vision	0	1	2	3	4
Light Sensitivity, Easily upset by bright light	0	1	2	3	4
Double Vision	0	1	2	3	4
Restlessness	0	1	2	3	4

Are you experiencing any other difficulties?

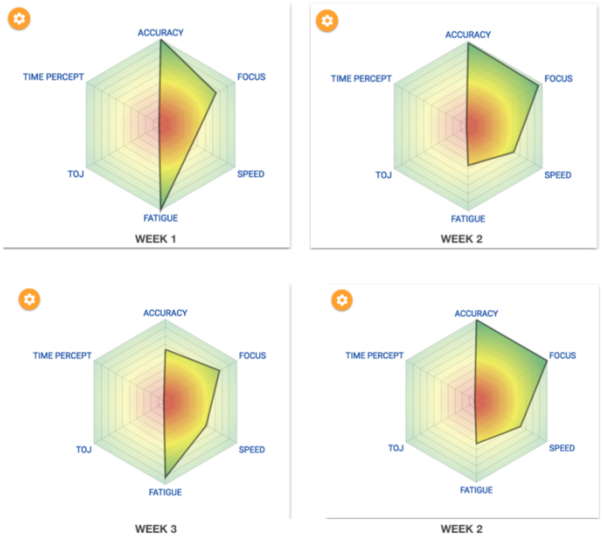
1. _____	0	1	2	3	4
2. _____	0	1	2	3	4

8.4 Appendix 4: Brain Gauge Radar Plots for participants

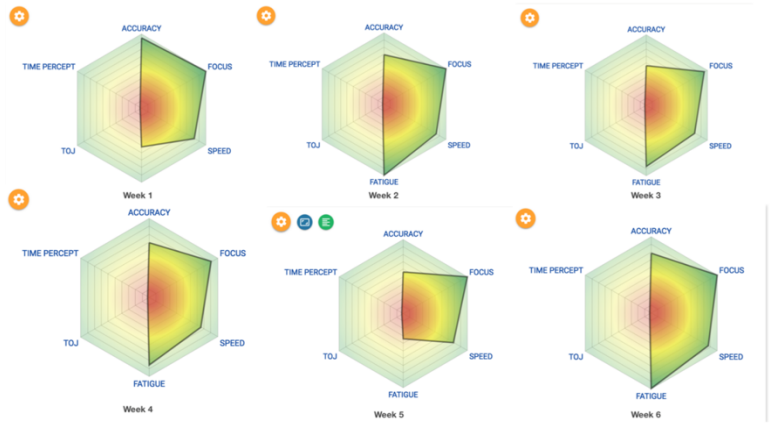
8.4.1 Participant A



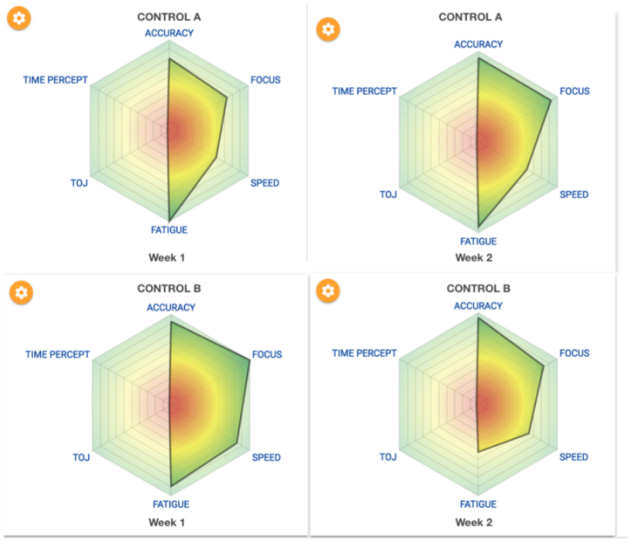
8.4.2 Participant B



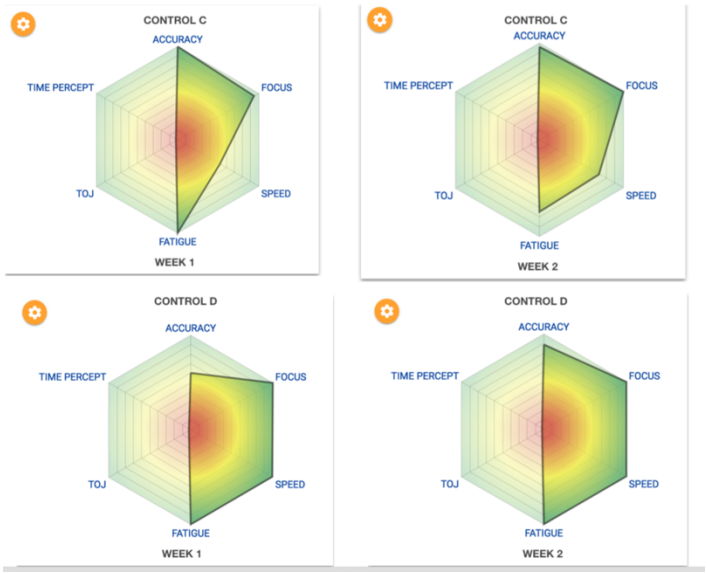
8.4.3 Participant D



8.4.4 Control A and B



8.4.5 Control C and D



9 Supplementary Information

9.1 Consent Form

Cumbria University

Fusehill St Campus,Carlisle, CA1 2HH
Telephone: 01228 616234
Email: s1611335@uni.cumbria.ac.uk

Study: Exploratory analysis of the effects of University Rugby on Brain health via sensory based assessment tools.

Researcher: Dylan Powell (MSc Student at the University of Cumbria) Mark Stigant Supervisor
Organisation: The University of Cumbria
Version: #CS012. 19:11:17
Participant Identification Number: ID no.

Informed Consent form for participants	**Please initial box**
I confirm that I have read and understand the information sheet and letter of introduction version dated 19:11:17 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.	☐
I understand that any information given by me may be used anonymously in future reports, articles or presentations by the research team.	☐
I understand that my name/personal information will not appear in any reports, articles or presentations.	☐
I will be asked to complete a) weekly brain health asssessments via BrainGauge devices b) weekly symptom monitoring questionnaire for a duration of 6 weeks.	☐
I understand that the researchers will have no say in team selection or medical assessement of players, including return to play decisions. All decision making will SOLELY be made by the University Rugby Coaches and associated medical team.	☐
I understand that if during participant testing, concerns arise surrounding welfare of players, e.g abnormal findings on BG test scores and or Rivermead questionnaire, appropriate action would be taken by Researchers to alert University Staff and/or medical professionals.	☐
I agree to take part in the above study.	☐

Name of Participant	Date	Signature
Name of Researcher Dylan Powell	Date	Signature

9.2 Information Sheet

Participant Information Sheet

University of Cumbria

Exploratory analysis of the effects of University Rugby on Brain health via sensory based assessment tools

About the study

Thank you for interest in the following study. The proposed research is investigating how brain health is affected during a university Rugby Union season. We will be using somatosensory devices (BrainGauge) supplied by Corticalmetrics. Brain Gauge's metrics are measurements of real brain function, and a symptom monitoring questionnaire to measure any changes.

Background to subject

Concussion is provoking intense debate in the public, legislative, sporting and medical communities. Direct impacts to the head such as those in rugby have been shown to be the main contributors to head injuries such as concussion. Despite the high number of player participation in University Rugby, little research has fully investigated the effect rugby has on brain health. The proposed study will use a somatosensory assessment tool (BrainGauge) to monitor and measure the effects a rugby season in a sample of university rugby union players (You) competing in the British University Colleges Sports (BUCS) . The next few pages of this document outlines how the study will be conducted. In addition there is a page which introduces the Braigauge device technology.

Hence the proposed study will start to address this shortcoming and provide a preliminary evaluation of the utility of BrainGauge devices to support physiotherapists and other medical professionals to better and more quickly identify players at risk of repeated concussions and develop return to play protocols to enhance safety in amateur Rugby Union.

1

Some questions you may have about the research project:

Why have you asked me to take part and what will I be required to do?
We are conducting a study requiring University rugby players (you). We would require participants to complete a weekly test using the Braingauge mouse throughout your rugby season. These tests would be completed at a laptop and ask you a series of questions These will be scheduled sessions mutually convenient and likley to coincide with team gym sessions/activities. In addition we would ask you to complete a symptom monitoring questionnaire every week throughout the season. Details of both of these area attached.

What will the test be like?
Whilst sitting at a laptop software will lead participants through a series of tests and will provide instructions for each one. All tests offer three practice trials to familiarise the participants with the testing procedure. You must answer all three correctly in order to continue. The research staff will be on hand if participants are stuck or require any help with the software. The laptop will be located in a private room, to provide confidentiality.

How much time am I expected to contribute/ is required?
A maximum of 15 minutes each week would be required of participants time.

Why should I take part In this study?
Despite the high number of young people participating in amateur rugby union, the level and potential risk associated with sports related concussion remains unexplored. At present, there is no established reliable quantitative method of assessing the impact that rugby union and other collision sports has on brain health. This study aims to monitor changes in the brain health of student rugby players over the course of a typical playing season. By taking part in this study, we hope to learn more about the effect rugby may have on Brain Health of Students across a University Rugby Season.

What if I do not wish to take part or change my mind during the study?

Your participation in the study is entirely voluntary. You are free to withdraw from the study at any time without having to provide a reason for doing so. If you decide to withdraw early from the study it is totally up to you if you wish to have your data withdrawn aswell. Equally it is permitable if you wish to have your data kept within the study for data analysis.

What happens to the research data?

All data will be anonymised using a numerical ID which completely anonymise the data. Participants will be able to receive the finished research paper after. All data collected will be kept on a monitored secure network and encrypted to maintain confidentiality.

If during participant testing, concerns arise surrounding welfare of players, e.g abnormal findings on BG test scores and or Rivermead questionnaire, appropriate action would be taken to alert University Staff and/or medical professionals.

Duty of Care for participants. Although this study is observational in nature we have a duty of care to raise any concerns where results indicate that participants are at risk of significant harm. To try mitigate the risk of harm to participants, It is important we as researchers report all adverse findings to a) participants b) those responsible for their medical care.

How will the research be reported?

It is our intention to publish the research, and present at appropriate conferences if succesfull.

How can I find out more information?

Please contact the research student directly Or alternatively contact Dylan's Supervisor Mark Stigant (mark.stigant@cumbria.ac.uk)
(Dylan Powell email, s1611335@uni.cumbria.ac.uk. If you would like to take part in the study please use the dedicated email rugbyunionhealth@gmail.com.

What if I want to complain about the research

Initially you should contact the researcher directly. However, if you are not satisfied or wish to make a more formal complaint you should contact my supervisor, if still not satisfied please contact Diane Cox, Director of Research Office, University of Cumbria, Bowerham Road, Lancaster, LA1 3JD. diane.cox@cumbria.ac.uk

9.3 Letter of introduction

University of Cumbria

Head Office

Fusehill Street
Carlisle, UK CA1 2HH

Tel: 01228 616234
Fax: 01228 616235
Mark.Stigant@cumbria.ac.uk

Date 13th November 2017

LETTER OF INTRODUCTION

Dear Sir/Madam,

This letter is to introduce Dylan Powell who is a Masters (pre-reg) student in the Physiotherapy Department at the University of Cumbria. He will produce his student card, which carries a photograph, as proof of identity.

He is undertaking research leading to the production of a thesis or other publications on the subject of Brain Health in University rugby players. He would like to invite you to assist with this project by agreeing to complete a weekly test using the BrainGauge which measures brain function or health. These tests will be scheduled sessions at mutually convenient times and likely to coincide with your team gym sessions/activities. In addition, we would ask you to complete a symptom monitoring questionnaire throughout the season. Details of both of these area attached. A maximum of 15 minutes each week across the 6 weeks would be required of participants time.

Be assured that any information provided will be treated in the strictest confidence and none of the participants will be individually identifiable in the resulting thesis, report or other publications.

Any enquiries you may have concerning this project should be directed to me at the address given above or e-mail (Mark.Stigant@cumbria.ac.uk)

Thank you for your attention and assistance.

Yours sincerely

Mark Stigant,

Senior Lecturer In Physiotherapy
University of Cumbria

9.4 Ethical Approval

Student signature: Dylan Powell **Date 3th November 2017**

Project supervisor: Mark Stigant **Date 23/11/17**

Comments: The documentation makes perfect sense to me now. The research itself is fairly passive, in that it will not change anything that the players are doing apart from using Brain Gauge and filling out questionnaires. Unforeseen, change in neurological status has been dealt with sensibly.

If this tool proves sensitive it should make both Physiotherapy, medical and coaching staff more able to make objective decisions regarding neurological status, which will potentially greatly improve player safety.

Programme Team/Module Leader:  **K.Morris Date 03/12/17**