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Electrophysiological and SCAT 5 characteristics of contact vs non-contact sport athletes

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Abstract

Introduction: There are a number of studies and systematic reviews suggesting potential chronic neurodegenerative effects of repetitive subconcussive head impacts. Indeed, most neuroimaging and some serum biomarker tests used in the literature generally present consistent evidence for negative effects of repetitive subconcussive head impacts. However, these tests have limited utility as side-line diagnostic tests. *Purpose*: Investigate whether two prospective side-line tests, sport concussion assessment tool 5 (SCAT 5) and transcranial magnetic stimulation (TMS), have enough sensitivity to detect relatively small and transient electrophysiological and cognitive changes in American football players who are very prone to repetitive subconcussive head impacts. The primary aim of this study is to investigate the effects of subconcussive head impacts on TMS and SCAT 5 performance by comparing contact with non-contact sport athletes. The secondary aim is to investigate the reproducibility and reliability of TMS and SCAT 5 in contact sport athletes. *Methods*: For the first section of the study, we assessed TMS and SCAT 5 measures on seventeen American football players (mean ±SD age: 23 ±7 years) and seventeen non-contact sport participants (mean ±SD age: 24 ±3 years) who were recruited for only one session. To assess the day-to-day reliability of each measure, the seventeen American football players were tested for a second time at least seven days following the first session. *Results*: Compared to the TMS day-to-day reliability analysis, SCAT 5 test scores presented poorer reproducibility and higher coefficients of variation (4–6% vs 10–66%, respectively). There were no significant differences in SCAT 5 test scores and corticospinal-silent period between contact and non-contact sport players. *Conclusion*: This is the first study to demonstrate similar electrophysiological and SCAT 5 characteristics between American football players and non-contact sport athletes. Also the electrophysiological changes observed are supported by our highly reliable and reproducible inter-day TMS data.

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1. Introduction

Over the last decade, there has been a surge in the literature regarding the potential negative effects of subconcussive head impacts on the brain tissue. Various papers have tried to define subconcussive head impacts. According to a recent review (Mainwaring et al., 2018), the most frequently cited definition is given by Bailes et al. (2013), and is defined as head impacts that do not result in a clinically diagnosed concussion but may be caused by rapid acceleration-deceleration of the brain. Evidence from systematic reviews (Bailes et al., 2013; Gavett et al., 2011) emphasizes the ubiquity of repeated subconcussive head impacts in contact sports, such as American football, hockey and soccer. For example, studies in soccer players suggest that repetitive heading of the ball may lead to an increased risk of chronic neurological injury (Fuller et al., 2006; Scott Delaney et al., 2006). Several papers have proposed that a series of metabolic, ionic and cytoskeletal disturbances trigger a pathological cascade in response to repetitive head trauma, which leads to the neurodegenerative changes characteristically seen in chronic traumatic encephalopathy (CTE)/dementia pugilistica (Giza et al., 2001; Yuen et al., 2009); whether associated with diagnosed concussion or not (McKee et al., 2009). A review by Gavett et al. (2011) further supports the association between repeated subconcussive head impacts and CTE by pointing out a history of repeated head injuries in all confirmed cases of CTE investigated by the year 2011. In light of the evidence presented above, it is imperative to understand the biomechanics and effects of subconcussive head impacts that lead to CTE, in order to device strategies to prevent the manifestation of CTE. The first step is to review the current literature around subconcussive head impacts in contact sports.

1.1 Literature review.

The following literature review discusses the various different measuring techniques employed to date in studying subconcussive head impacts in contact sports, which will help determine whether there is enough evidence to suggest the potential negative effects of subconcussive head impacts.

1.1.1 Neuropsychological and balance tests.

Crisco et al. (2011) recruited 314 players from the National Collegiate Athletic Association (NCAA) football programs who were tested over 3 seasons (2007 – 2009). Players were monitored for head impacts by fitting the head impact telemetry (HIT) system in their

helmets, which computes linear and rotational accelerations as well as impact location. The authors reported that during a single season, the total number of impacts received by an individual player was a median of 420 (217 -728). Impacts to the top of the head were the least frequent, and were associated with the greatest peak linear acceleration magnitudes ($P<0.05$), but significantly lower peak rotational acceleration magnitudes than all locations for all player positions (Crisco et al., 2011). Impacts to the back of the helmet tended to be of the highest magnitude and were significantly ($P < 0.05$) more frequent for quarterbacks and wide receiver than for all other positions. Although this study provides insightful information about the magnitude and frequency of head impacts in American football athletes, the authors did not correlate these impact biomechanics to neuropsychological or physiological performance changes.

On that note, McAllister et al. (2012) recruited 214 division I NCAA football and ice hockey players and 45 non-contact sport control players to investigate the effects of repetitive head impacts on cognitive performance over one season. The participants performed an extensive battery of neuropsychological tests which included the computerised immediate post-concussion assessment and cognitive testing (ImPACT) and seven other neuropsychological measures, at pre-season and post-season. The helmets of football and ice hockey players were fitted with the HIT system. Pre-season ImPACT scores were similar between non-contact and contact sport players. Contact sport athletes performed more poorly at pre-season but better at post season in the paced auditory serial addition task (PASAT) concentration test, compared to non-contact athletes (McAllister et al., 2012). However, a statistically significant higher percentage (24% vs 4%) of a subgroup of contact sport athletes performed below their predicted score on the post-season California verbal learning test (CVLT-II: Delis et al., 2000), which is a measure of verbal and visual learning and memory. Although the poorer postseason CVLT-II test scores did correlate with greater head impact exposure, statistical significance was not proven (McAllister et al., 2012). The only statistically significant relationships were between head impact exposure (HIE) metrics and Trails 4/B test (a measure for visual attention and task switching), as well as between season peak linear acceleration and ImPACT reaction time composite score. Therefore, the authors concluded that the frequency of head impacts over a single season of collegiate contact sports does not have a widespread short-term detrimental effect on all athletes.

In a comparable study, Miller et al. (2007) used standardised assessment of concussion (SAC) along with ImPACT on 76 Division III collegiate football players. Even

though non-concussed football players were likely to be exposed to repetitive subconcussive head impacts, there were no significant declines on the SAC or ImPACT over the season (Miller et al., 2007). On the contrary, statistically significant improvements were seen as the season progressed in total SAC score, immediate memory and concentration, as well as significant improvements in visual memory and reaction time of ImPACT (Miller et al., 2007). Although the authors did not measure head impacts, the results from this study suggest that the neuropsychological tests used were not sensitive enough to detect any negative effects of repetitive sub-concussion forces.

In support of the above conclusion, a study investigated the ability of ImPACT and functional magnetic resonance imaging (fMRI) to accurately identify significant diagnosis of high school football players sustaining a high number of sub-concussive head impacts measured by HIT system (Breedlove et al., 2014). The authors observed that many participants were flagged without sustaining large numbers of hits, which suggests that the lower scores of players flagged by the ImPACT may not be representative of real neurocognitive deficits, pointing to false-positive results (Breedlove et al., 2014).

Gysland et al. (2012) employed a battery of neurocognitive and balance tests to assess neurocognitive and postural performance in 46 male collegiate football players at pre-season and post-season. Head impact biomechanics were measured with the HIT system. Subjects completed a quasi-randomized testing order of each of five testing measures (Automated neuropsychological assessment metrics [ANAM] (Bleiberg et al., 2000), SAC (McCrea et al., 1997), sensory organisation test [SOT] and balance error scoring system [BESS] to assess balance performance, and graded symptom checklist [GSC]). Over one season, head impact variables did not explain the changes in neurocognitive performance in ANAM or SAC (Gysland et al., 2012). Also, there were contradicting findings amongst the balance tests. For example, in BESS, a higher cumulative magnitude of head impacts was predictive of higher (worse) BESS scores over the season. However, a higher number of impacts and number of prior concussions were predictive of improved BESS performance over the season (Gysland et al., 2012). In addition, the higher the number of years playing experience, there were lower predictive SOT score (worse) over the season. In the graded symptom checklist, the independent impact variables did not predict changes in total severity scores over the season, thus it is potentially not clinically meaningful (Gysland et al., 2012). Also the SOT had a less than one point difference, which suggests there were no clinically meaningful postural deficits.

Miyashita et al. (2017) used a different population group to investigate the effects of subconcussive head impacts on balance performance. They assessed pre- and post-season BESS performance in 34 division I male lacrosse players, whose helmets were fitted with the GForce tracker sensor which measures linear acceleration and rotational velocity, similar to the HIT system mentioned in the previous studies. The authors found that 11 of the players had an increase in their total number of errors on the post-season BESS test by 7 or more, but there was no significant correlation between total number of BESS errors and HIE data (linear acceleration and rotational velocity). The investigators were counting BESS errors on foam and flat surfaces based on the presence of the following conditions; 'hands moving off hips, opening eyes, falling, stepping, abduction or flexion of the hip beyond 30°, lifting foot off the testing surface, and/or remaining out of the proper testing position for longer than 5 seconds' (Miyashita et al., 2017). The total number of errors on foam surface, however, was found to have a significantly positive relationship with HIE data (Miyashita et al., 2017). Thus the authors explained that the balance deficits observed on the foam surface may indicate vestibular system dysfunction associated with cumulative head impacts.

The potential for vestibular dysfunction as a result of repetitive subconcussive head impacts was further investigated in a recent study using a repeated measures experimental design with three time sessions (pre-heading, immediately post heading and 24 hours post-heading). The authors assessed changes in vestibular processing following performance of 10 headers in 20 healthy adults with at least 5 years of soccer experience, using galvanic vestibular stimulation [GVS] (Hwang et al., 2017). Immediately after the acute subconcussive head impact, GVS during standing showed a consistent deficit in vestibular processing which recovered to pre-heading levels after 24 hours. This transient vestibular processing deficit during standing, seen in the experimental group, means that their standing postural control was less responsive to GVS, which suggests that vestibular processing was disrupted by the subconcussive impacts (Hwang et al., 2017). Both Miyashita et al. (2017) and Hwang et al. (2017) provided promising findings for the potential utility of vestibular processing as an addition to a more comprehensive battery of side-line tests for immediate on-field concussion diagnosis.

In summary, studies to date using neuropsychological tests in contact sports have failed to detect any significant and/or consistent negative relationship between head impact biomechanics (frequency and magnitude of subconcussive head impacts) and changes in neuropsychological performance (McAllister et al., 2012; Miller et al., 2007; Gysland et

al., 2012). This observation is in agreement with a systematic review by Belanger et al. (2016), who concluded that any negative effect of subconcussive head impacts is potentially 'small and non-replicable'.

1.1.2 Neuroimaging tests

A different set of studies explored the potential utility of neuroimaging techniques in investigating the effects of subconcussive head impacts. For example, one study used diffusion weighted imaging (DWI), CVLT-II and wide range achievement test (WRAT-4) in collegiate varsity football and ice hockey players with no history of reported concussion; and non-contact sport athletes between pre-and post-season over 4 seasons (McAllister et al., 2014). Pre-season to post-season mean diffusivity (MD) in the corpus callosum decreased in the non-contact sport, whereas it increased in the contact sport athletes (McAllister et al., 2014). In addition, post-season fractional anisotropy (FA) and MD, which are indicators of axonal function, significantly differed between groups in the amygdala. These data however, were not presented in the study (McAllister et al., 2014). The significant association seen between head impact metrics and postseason white matter measures in corpus callosum, amygdala, cerebellum and hippocampus suggests that those brain regions may be affected by repetitive head impacts even in the absence of diagnosed concussion. The findings also suggest that the frequency and magnitude of the head impacts can modulate changes in white matter diffusion measures (McAllister et al., 2014). Also, 16 out of 80 contact sport athletes and 9 out of 79 noncontact sport athletes performed poorer at the postseason assessment on the CVLT-II, a measure of verbal learning and memory (McAllister et al., 2014). The poorer performance on the post-season CVLT-II was significantly associated with a greater degree of change in MD in the corpus callosum ($p = 0.017$) relative to the normally performing group of athletes (McAllister et al., 2014). Despite the consistent associations shown above, there was significant variability among the athletes. The authors postulated that repetitive head impacts in some individuals may affect white matter changes in some brain regions differently, depending on the frequency of head impacts and their relationship to the time of imaging (McAllister et al., 2014).

Another study using DWI investigated white matter changes in two teams of male high school football players over 2 seasons, using athletes participating in non-collision sports as a control group (Chun et al., 2015). Imaging sessions were performed before practices (pre-season), once during each half of the season and once post-season. Head

impact exposure was measured with HIT system. Both teams were exposed to repetitive subconcussive head impacts and presented significant changes in post-season FA (Chun et al., 2015). Specifically, team 1 had a significant increase in FA, whereas team 2 had a significant decrease in FA from pre- to post-season (Chun et al., 2015). Also mean FA values exhibited statistically significant linear trends in athletes experiencing repetitive head impacts throughout the competition period. The authors suggest that the differences in the direction of FA changes between the two teams may be associated with different axonal insults at the later stages of brain injury (Chun et al., 2015). For example, the increased FA in team 1 may suggest that the higher frequency of low magnitude head impacts has resulted in axonal inflammation (Chun et al., 2015), whereas the less frequent head impacts of higher magnitude experienced by team 2 may have been more damaging to the fiber structure (Chun et al., 2015).

ImPACT and fMRI tests were also employed in a different study to investigate the effect of subconcussive head impacts on male high school football players pre- and post-season, with some players invited for in-season assessments (Talavage et al., 2014). Subconcussive impacts were measured using the HIT system. The authors categorised the participants based on the behavioural deficits they exhibited during the study. The categories were, clinically-observed impairment (COI+), which included participants with clinically diagnosed concussions; and functionally-observed impairment (FOI+) which included participants flagged by the neuropsychological test. There were 4 diagnosed concussions during the study, of which 3 concussed participants performed significantly worse on one or both of the verbal and visual memory composite scores on ImPACT and were-categorized as COI+/FOI+ in the study (Talavage et al., 2014). Of the players who completed in-season assessments, 8 did not have a diagnosed concussion (COI-), but 4 of the 8 players exhibited significant reductions in verbal and/or visual memory scores on ImPACT, from pre-season to in-season assessment, and were categorised as COI-/FOI+ (Talavage et al., 2014). The COI-/FOI+ subgroup exhibited a high frequency of high magnitude (> 80g) head impacts to the top front of the helmet, which were associated with the significantly decreased fMRI activation levels in the dorsolateral prefrontal cortex (DLPFC) and cerebellum regions (Talavage et al., 2014). These regions are strongly associated with working memory, which is believed to affect attention and in turn the quality of athletes' decision making during the game (Zhuang et al., 2018). In comparison with the clinically diagnosed concussed players, the COI-/FOI+ players had at least just as impaired ImPACT performance scores and fMRI data, however activation areas detected

by fMRI were different (Talavage et al., 2014). The findings of this study suggest that even though both the concussed group of players (COI+/FOI+) and the COI-/FOI+ subgroup exhibited neurocognitive (ImPACT) and neurophysiological (fMRI) deficits, their injuries differed in mechanism and location. Regarding the concussed group, the deficits observed were a result of brain damage caused by a single deleterious collision event; whereas for the COI-/FOI+ subgroup the deficits observed were characteristic of subconcussive head impacts (Talavage et al., 2014).

Another neuroimaging technique employed to assess the effects of subconcussive head impacts is proton-magnetic resonance spectroscopy (H1-MRS). Bari et al. (2018) used the H1-MRS in male and female players from two high school collision sports (football and soccer), who were imaged 5 times per season over two seasons. The authors also recruited male and female players from non-collision sports as the control group. Sports included swimming, tennis and basketball and participants were assessed two times during their season. All collision sport participants had xPatch sensors attached to them for monitoring head acceleration events. The authors found that during periods of considerable head impact exposure, asymptomatic football and soccer players had statistically significant neurometabolic changes in DLPFC and motor cortex, respectively (Bari et al., 2018). Further, the neurometabolic alterations observed in football athletes during the second half of the season were found to be significantly associated with the accumulation of events exceeding a force of 50 g (Bari et al., 2018). Soccer players also exhibited significant increases in metabolite concentrations during the season. However, these changes were not associated with their significantly fewer subconcussive head impacts compared to football (Bari et al., 2018).

Diffusion kurtosis imaging (DKI) has also been used to investigate the effect of subconcussive head impacts on white matter integrity, by taking into account the anisotropic and non- Gaussian diffusion that naturally occurs in the brain. In a study by Davenport et al. (2016), 24 male high school football players were assessed pre-and post-season on DKI and ImPACT neuropsychological test. Head impact biomechanics and exposure were measured through the HIT system, which calculated the risk weighted cumulative exposure (RWE) metric. RWE combined probability (RWEcp) was the main determinant of white matter changes and was based on the combined probability associated with the peak resultant linear and rotational acceleration components of each head impact (Davenport et al., 2016). The authors found a positive association between increased RWEcp and the increased number of abnormal DKI metric voxels, in the absence of

clinically diagnosed concussion. The strong positive association between mean kurtosis (MK) and RWEcp suggested astrogliosis, while the strong positive association between intra-axonal diffusivity (Da) and RWEcp, was suggestive of axonal beading and cytotoxic edema (Davenport et al., 2016). The magnitude of changes from pre- to post-season ImPACT composite scores did not have any statistically significant associations with the number of abnormal DKI metrics, which suggests that changes in DKI metrics may present brain changes before they become clinically identifiable (Davenport et al., 2016).

However, in a more recent study also employing DKI, the authors showed supporting findings (Gong et al., 2018). The authors recruited 16 male high school football players, who were assessed on pre- and post-season DKI and neuropsychological test over one season (Gong et al., 2018). The results showed significant microstructural changes over one season of football, in the rostral middle frontal cortices (cortical region) and in deep gray matter nuclei of thalamus as reflected by decreased mean kurtosis (MK) and increased MD metrics (Gong et al., 2018). The frequency of front head impacts was negatively correlated with changes in the posterior cortical gray matter as seen by changes in MK, whilst there was no association of either MK or MD with changes in the rostral middle frontal cortices; suggesting that injury on the opposite side of the head impact (contrecoup injury), may be the dominant mechanism for changes in microstructure pre- to post-season (Gong et al., 2018).

Abbas et al. (2015) recruited 22 high school football athletes during the 2011 season, along with 10 non-collision sport, high school athletes. The non-collision sport athletes underwent 2 imaging sessions (resting-state functional magnetic resonance imaging [rs-fMRI]) separated by 4-6 weeks. Collision sport athletes participated in at least 3 sessions during pre-season, at least once during the season and once post-season (Abbas et al., 2015). The helmets of the football athletes were fitted with HIT system to monitor head impacts during each practice and game. The authors observed that during the first month there was a high rate of total hits, followed by relatively stable high magnitude impacts between the first and third months. The highest magnitude hits and the highest number of hits were seen in the last month of the season (month 4) (Abbas et al., 2015). Asymptomatic and non-concussed football players exhibited increased functional connectivity in rs-fMRI over periods of high number of hits and high magnitude impacts compared to non-collision sport cohort and their own baseline measures (Abbas et al., 2015). However, these changes in functional connectivity occurred even during periods of no head impact events (pre-season and post-season assessments) supporting the

observation of connectivity changes 5 months after the season and may suggest that repetitive subconcussive head impacts can potentially have a cumulative long-term effect on brain connectivity (Abbas et al., 2015).

In summary, neuroimaging studies have been more consistent in demonstrating the potential negative effect of repetitive subconcussive head impacts on the brain (McAllister et al., 2014; Chun et al., 2015; Talavage et al., 2014; Bari et al., 2018; Davenport et al., 2016; Gong et al., 2018; Abbas et al., 2015). Several neuroimaging studies showed that repetitive subconcussive head impacts can negatively affect axonal function, white matter integrity and brain activity even in the absence of diagnosed concussion (McAllister et al., 2014; Davenport et al., 2016; Talavage et al., 2014). Another study showed that there might be a threshold on the amount of subconcussive head impact exposure before a deleterious effect is observed (Bari et al., 2018), while a different neuroimaging study proposed that repetitive subconcussive head impacts can potentially have a cumulative long-term effect on brain connectivity (Abbas et al., 2015).

1.1.3 Serum biomarkers

A different cluster of studies investigated the effects of subconcussive head impacts on different serum biomarkers. When an athlete receives a head insult, the body goes through two major phases (Agoston et al., 2017). The primary phase consists of the direct consequences of the impact on the brain including disruption of axons, neurons and cell membranes (Newcombe et al., 2016). In the secondary phase the body attempts to repair and restore structural integrity in the injured areas (Newcombe et al., 2016). Therefore, the secondary phase consists of metabolic, vascular and axonal changes as well as inflammation (Prins et al., 2016; Hill et al., 2016; Johnson et al., 2013; Finnie, 2013; Simon et al., 2017), with each process presenting unique biomarker profiles that can provide molecular information about the nature of damage to the central nervous system (Sharma and Laskowitz, 2012). In a recent study, head impact biomechanics and serum blood samples of S100 calcium-binding protein B (S100b) were measured in 22 division I football athletes at 5 time points, including one session pre-training camp practices and four full contact sessions during training camp taken pre and post practice (Kawata et al., 2017). Players were fitted with Vector mouth guard to measure frequency and magnitude of head impact accelerations. S100b protein is involved in the regulation of a number of cellular processes such as cell cycle progression and differentiation.

The authors found that players with higher cumulative head impacts were significantly associated with a higher pre to post-practice increase in S100b levels (Kawata et al., 2017). They also found that even though there were no differences in symptom scores between higher and lower impact groups over time, S100b levels in the higher impact group increased from baseline to all post-practice time points. There was no significant increase observed in the lower impact group from baseline to all pre- and post-practices (Kawata et al., 2017).

A more recent complementary study employed the same study design used in Kawata et al. (2017) in order to investigate the effects of head impacts on Tau and S100b serum biomarkers in 23 non-concussed division I collegiate football players (Kawata et al., 2018). Changes in serum S100b levels were associated with frequency and magnitude of impacts received (Kawata et al., 2018), which is in agreement with the results in Kawata et al. (2017). Tau proteins are abundant in the neurons of the central nervous system and play a role in stabilizing microtubules. The authors showed that the frequency and magnitude of subconcussive head impacts was not associated with increases in Tau concentration (Kawata et al., 2018). The magnitude of the acute serum total Tau changes was also found to steadily decline in full contact practices over time, even though players were exposed to a higher frequency and magnitudes of repetitive subconcussive head impacts compared to pre-training camp practices (Kawata et al., 2018).

Another serum biomarker used to investigate effects of subconcussive head impacts is neurofilament light protein (NF-L). To achieve this, Oliver et al. (2016) recruited 116 NCAA division I American football athletes who were separated into starters and non-starters, and 19 NCAA division I swimmers as controls. Blood samples of NF-L were taken at baseline with no contact training and 7 more blood samples were taken at pre and at different times during training camp. The serum concentration of NFL increased significantly throughout the season in starters, with substantial increases seen during periods of increased sub-concussive head impacts (Oliver et al., 2016). Specifically, the first increase was during post-camp, followed by a substantial increase during conference play which remained elevated until the end of the season (Oliver et al., 2016). The moderate to large magnitude of increase in serum NFL during periods of increased sub-concussive head impacts suggests that the cohort of collegiate football players in this study may suffer from some level of axonal injury, which likely causes release of NF-L from neurons (Oliver et al., 2016). This hypothesis is supported by another study that suggested that due to the role NFL plays in the structural support of the axonal skeleton of neurons, it

can be a sensitive and specific biomarker in detecting neuro-axonal injury in concussion (Zetterberg et al., 2013)

More recently, Oliver et al. (2018) employed a similar study design that was used in a previous study (Oliver et al., 2016), to investigate changes in the concentration of Tau, as well as NF-L, in a group of NCAA division III American football athletes separated into starters and non-starters. Even though Oliver et al. (2018) did not include a control group, they provided reinforcing evidence about the increased serum NF-L in starters above pre-training levels as a result of higher subconcussive head impacts. They also showed that it was significantly higher compared to non-starters, over the course of the season (Oliver et al., 2018). In regards to changes in the serum concentration of Tau over the course of the season, the authors found a decrease in both starters and non-starters, compared to pre-training, (Oliver et al., 2018). Also, serum Tau failed to differentiate between starters and non-starters, and this finding is supported by Kawata et al. (2018) who found no association between increased Tau and subconcussive head impacts. Even though serum NF-L had poor accuracy in identifying athlete status during pre-training assessment, it showed fair to moderate accuracy once repetitive head impacts began (Oliver et al., 2018).

A different group of researchers employed an extensive array of serum biomarkers and neuropsychological battery of tests in 16 varsity high-school football players (Joseph et al., 2018). The players performed pre-season neuropsychological assessment and blood sampling, with two more assessments, one immediately after the game when a high acceleration impacts (HHI) was observed and one after the last game of the season. The helmets of all athletes were fitted with Riddell HIT system to record head impact data during all practices and games. Assessments taken immediately after the game showed a significant increase in serum Tau and ubiquitin carboxyl-terminal hydrolase L1 (UCH-L1) in HHI group compared to non-HHI group, and were positively correlated with maximal rotational acceleration (Joseph et al., 2018). There were no significant differences in NF-L; glial fibrillary acidic protein (GFAP); or calpain and Spectrin Breakdown Products (SBDPs) between HHI and non-HHI. Post-season assessments showed significant increases in Tau and UCH-L1 levels, which were suggestive of neuronal and axonal injury in asymptomatic, non-concussed athletes (Joseph et al., 2018). However, since none of the biomarkers had a significant correlation with accelerometer metrics pre- and postseason, the study could not explain the collective findings because there were also no deficits in post-season neuropsychological assessments and athletes did not present any symptoms (Joseph et al., 2018).

In summary, negative effects of subconcussive head impacts have been detected in some serum biomarker studies but not in others. Studies found serum concentrations of S100b and NF-L biomarker to have a significant association with high cumulative subconcussive head impacts (Kawata et al., 2017; Kawata et al., 2018; Oliver et al., 2016 and Oliver et al., 2018). Whereas, serum concentrations of Tau and UCH-L1 proteins were not associated with frequency and magnitude of subconcussive head impacts (Kawata et al., 2018; Oliver et al., 2018 and Joseph et al., 2018).

1.1.4 Limitations of neuroimaging and serum biomarker tests.

With the exception of neuropsychological tests, most neuroimaging and some serum biomarker tests presented above provided evidence for the negative effects of subconcussive head impacts; however these measuring techniques are limited in their potential to be used as side-line tests for concussion diagnosis. For example, DKI requires specific conditions like faster acquisition, very strong gradients and perfect field homogeneity, which are not possible with the existing hardware and power requirements therefore limiting the DWI accuracy and resulting in image distortion and limited morphological interpretability (Chilla et al., 2015). While fMRI and rs-fRMI are too expensive and they focus on blood flow in the brain which does not provide direct information about the activity neurons that are critical to assessing mental function. DKI requires high acquisition and post-processing time that make it impractical for quick on-field side-line assessments; while H1-MRS analysis requires a neuro-radiologist and it is also too expensive for frequent measures when monitoring return to play after concussion. Serum biomarkers are limited for side-line use in that they require specialised analysis by trained staff, and the analysis is expensive.

1.2 Alternative candidate tests for side-line assessment.

Therefore, it is necessary to find other more efficient, reliable and stable diagnostic tools that can be used as side-line tests for assessing asymptomatic players following alarming subconcussive head impacts.

1.2.1 SCAT 5 and improvements since SCAT 3

Recently an updated version of sport concussion assessment tool, version 5 (SCAT 5) has been proposed for side-line diagnosis of concussion during games as well as to monitor the

graduated return to play protocol. However, SCAT 5 has not been yet evaluated for its reliability and repeatability. SCAT 5 is revised from SCAT 3, which was released in 2012. The new version includes more extensive list 'red flag' symptoms that require immediate management following a direct or indirect head impact. Also the Maddock's memory assessment questions and Glasgow coma scale (GCS) are the same as SCAT3, with the addition of optional repeat testing for GCS. Cervical spine assessment is new in SCAT 5 to assess the possibility of spinal injury, and it provides further instructions in case the athlete is not fully conscious, that cervical spine injury should be assumed until proven otherwise. Symptom evaluation is also updated since SCAT 3, which had the athletes verbally rank symptoms read to them by the investigator; to SCAT 5, which involved handing them the symptom form and asking them to complete the symptom checklist themselves. This change in the symptom evaluation was believed to improve honesty of reporting symptoms if athletes are not asked about them. The immediate memory section in SCAT 5 has more alternative word lists and the option to choose 10 words rather than just 5 as in the case of SCAT 3. The time of testing the immediate memory is also added to SCAT 5 to assess how long it takes to do the delayed recall test. In concentration score, SCAT 5 makes it clear that the investigator should not use the same string of numbers when an athlete fails to recall them, and it provided more lists than SCAT 3. The neurological screening merges the neck exam and coordination exam of SCAT 3 together, and adds some different central nervous system questions, which include ability to read aloud, follow instructions and movement of eyes up-down and side-to-side without double vision. Also tandem gait is also moved to this section. The tandem gait in SCAT 5 is not optional, also not timed and does not involve trials, unlike SCAT 3. SCAT 5 provides clearer instructions on how to conduct the delayed recall test and how much time passed since the immediate memory test. The final decision section regarding SRC diagnosis and/or fitness to play is a medical decision based on clinical judgement (McCrory et al., 2017). Also for the graduated return to play protocol, SCAT 5 suggests that after a brief period of rest 24–48 hours after injury, the athletes are encouraged to become gradually and progressively more active, rather than complete rest as seen in SCAT 3, however the activity level should not cause or worsen their symptoms (McCrory et al., 2017).

1.2.2 Transcranial magnetic stimulation (TMS)

Another potential tool for side-line assessment is TMS, which has demonstrated utility and high sensitivity in detecting electrophysiological alterations as a result of

concussion (Major et al., 2015; Pearce et al., 2015; Miller et al., 2014; De Beaumont et al., 2007). Corticomotor inhibition is considered the most consistent TMS marker of concussion and is expressed as a longer corticospinal silent period, which is the amount of time taken for the TMS pulse to travel from the brain to the target muscle [refer to section 2.5] (Major et al., 2015; Pearce et al., 2015; Miller et al., 2014). The increased corticomotor inhibition is associated with increased activity of the gamma-aminobutyric acid b (GABAb) receptor pathway, as measured by single pulse TMS, and is believed to reflect short- and long-term consequences of brain injury (De Beaumont et al., 2009; Tremblay et al., 2011; McDonnell et al., 2006). The utility of TMS in detecting acute electrophysiological changes following subconcussive head impacts is a relatively new concept in the literature, reflecting the difficulty in interpreting clinically meaningful effects due to the scarcity of studies in this context. In turn, there are no observational studies to my knowledge that have employed TMS and/or SCAT 5 to investigate the effect of subconcussive head impacts experienced from participation in contact sports. One study to date found a transient increase in corticospinal silent period ('5.4 ± 4.8%') immediately following a bout of 20 headers, which returned to baseline by 24 hours post-heading (Di Virgilio et al., 2016). The authors also investigated the day-to-day reliability of TMS in soccer players and healthy adults, which was found to have good reliability (Di Virgilio et al., 2016). Nevertheless, there is lack of data about the reliability and reproducibility of SCAT 5 and TMS in American football athletes.

1.3 Purpose and aims of study

The purpose of my study is to investigate whether TMS and SCAT 5 have the sensitivity necessary to detect relatively small and transient electrophysiological and cognitive changes, which is necessary to establish in American football players since they are very prone to repetitive subconcussive head impacts. Interestingly, this is the first study that has attempted to investigate the utility and sensitivity of SCAT 5 in subconcussive head impacts.

Therefore, the primary aim of the study is to investigate the effects of subconcussive head impacts on TMS and SCAT 5 performance by comparing contact with non-contact sport athletes. The secondary aim is to investigate the reproducibility and reliability of TMS and SCAT 5 in contact sport athletes by assessing them on two different sessions separated by at least a week. We hypothesise that the contact sport participants

would have longer corticospinal-silent periods and lower SCAT 5 performance in the single leg balance test, immediate memory score, concentration score and delayed memory score, compared to non-contact sport athletes; and that the TMS technique would be more reliable and consistent compared to SCAT 5.

2. Methodology

2.1 Participants and ethical approval

2.1.1. Comparison of contact with non-contact sport participants

We recruited 28 male athletes from the University of Stirling American football team, via direct communication channels with the team's head coach. From those recruited only 18 agreed to baseline testing (mean ± SD age, 23 ± 7 years; body mass, 96.6 ± 21.3 kg; stature, 182 ± 6 cm). One of the American football participants who agreed to be baseline tested had attention deficit hyperactivity disorder and was not able to complete any of balance tests in the modified BESS (mBESS) of SCAT 5 during both sessions; therefore he was excluded from all analysis. Thus the final baseline cohort consisted of 17 participants in total. The 17 American football players were compared to a control group consisting of 17 (15 males and 2 females) healthy, active participants (mean ± SD age, 24 ± 3 years; body mass, 73.0 ± 9.0 kg; stature, 177 ± 8 cm) who were either playing non-contact sports (touch rugby & water polo), or exercising at least 2 times a week, for 45-60 minutes per day.

2.*1.2. Day-to-day reliability study*

The 17 American football players were also required to report to the laboratory for a second session to assess the reproducibility and reliability of TMS and SCAT 5 measures. The American football players recruited in this study participated in a total of 10 games, including both league and knockout fixtures, during the 2017-18 season. The trial sessions were performed within 48 hours after the 6^{th} and 7^{th} games, or within 24 hours following practices, depending on the players' availability.

2.1.3. Ethical approval

The study was approved by the local NHS, invasive or clinical research (NICR) ethics committee and procedures conformed to the guidelines set out by the Declaration of Helsinki. All participants signed an informed consent form within 48 hours of receiving the participant information sheet, before taking part in the study.
Participants completed a screening questionnaire and were excluded from participating if they had any of the following high risk factors: 1) history of brain injury resulting in loss of consciousness; 2) history of a neurological condition; 3) history of epilepsy, seizures, fainting spells in the past; 4) family history of epilepsy or seizures; 5) use of psychoactive recreational or prescription drugs; 6) electrical devices fitted to their body (such as pacemakers, cochlear implant, medication pump, surgical clips, neurostimulator); 7) metal implants in the skull; or 8) undergone any type of neurosurgery procedure (including eye surgery).

2.2 Study design

All participants were asked to have their normal diet for the day of the session and not eat at least 1 hour prior to their session. They were also asked to refrain from vigorous physical activity, consumption of alcohol, caffeine or smoking for 24 hours prior to the session. All testing was carried out on the non-dominant leg of the participant, in agreement with SCAT 5 single leg stance balance test.
All participants from both contact and non-contact sport groups completed the same tests in the same order as shown in Figure 1. We did not include a familiarisation session since the participants were involved in similar neuromuscular studies carried out in the University of Stirling prior to the present study and they were already familiar with the measures of the study. Also non-contact sport, control participants were not tested for a second time because there is existing evidence for the reliability of TMS in a cohort of healthy, control participants recruited from the University of Stirling (Di Virgilio et al., 2016).

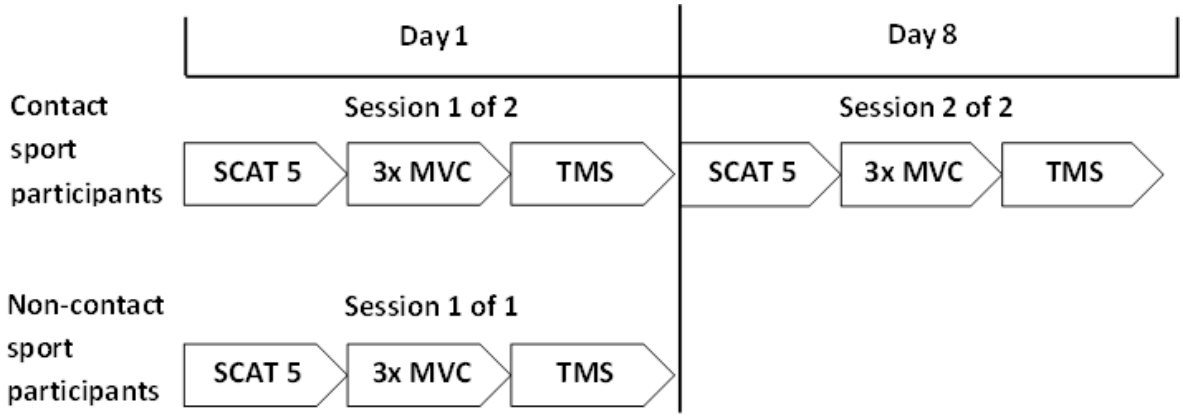

Figure 1: Timeline schematic for the order of tasks completed by both contact and non-contact sport participants in their sessions. The contact sport participants completed a second session 7 days after their first session.
SCAT 5: sport concussion assessment tool version 5; MVC: maximum voluntary contraction; TMS: transcranial magnetic stimulation.

2.2.1 Comparison of contact with non-contact sport participants

The non-contact sport participants in the control group were required to report to the laboratory for only one session (Figure 1). Therefore, the TMS and SCAT5 tests of the first session of the contact sport group (Session 1 of 2; Figure 1) were compared to the only session of the non-contact sport group (Session 1 of 1; Figure 1).

2.2.2 Day-to-day reliability study

The American football players were required to report to the laboratory two times separated by at least 7 days. We tried to keep the two sessions of each participant on the same day and time during the two separate weeks. To examine the day-to-day reliability and reproducibility of the TMS and SCAT 5 tests, session 1 of day 1 was compared to session 2 of day 8 (Figure 1). It should be noted that one participant from the final baseline cohort did not complete his second session due to knee pain on the trial leg, so he was only excluded from the day-to-day reproducibility and reliability analysis.

2.3 Sports Concussion Assessment Tool 5 (SCAT 5)

SCAT 5 is a revised version of the SCAT3, which is recommended for assessing acute sports concussion on-field by the Berlin Consensus statement on concussion in sport (McCrory et al., 2017). SCAT 5 includes the following measures: symptom evaluation (post-concussion symptom scale [PCSS]), cognitive screening (SAC), concentration, neurological screening, balance examination (mBESS) and delayed recall. The SCAT 5 was followed according to the instructions provided at the end of the journal (Sport

concussion assessment tool-5th edition, 2017). A copy of the SCAT 5 assessment can be found in Appendix 1.

2.3.1 Symptom evaluation (PCSS)

The symptoms are measured using a 22-item PCSS, and each item uses a 7 point Likert scale from 0-6 to determine the severity of each symptom. The maximum number of symptoms is 22 and the maximum severity score is 132.

2.3.2 Cognitive screening (SAC)

Cognitive screening consists of orientation, immediate memory, concentration and delayed recall tests. The orientation test consists of 5 basic questions with each correct question scoring 1 point for a total of 5. The orientation test scores were not included in the analysis, because the mean score achieved by both contact and non-contact sport groups was 5, which is the maximum possible score.

The immediate memory test has two groups of word lists; the first group consists of 5 words and the second group of 10 words. The participants are required to recall as many words as they can from the list read to them, over a total of 3 trials. Thus the maximum score for the 5 and 10 word lists is 15 and 30, respectively. In order to minimise any ceiling effect, we used a 10 word list first and if the participant could not recall more than 5 words, we would switch to the 5 word list for the second and third trials using the same first five words in the list. For this test, and the delayed recall test, we had pre-recorded each list with one of the lecturers from the faculty (Dr Iain Gallagher) via a voice recorder application on the phone, in order to ensure that the tempo of each list was uniform among all participants.

The concentration score consists of two parts. The first part involves a list of strings of numbers, which are read to the participants who have to repeat each string of numbers in the reverse order. The participants are given two attempts at a specific string length with different numbers and are only progressing up the list if they get at least one of the two attempts correct. For each correct attempt a score of 1 is given, for a total of 4. The second part requires the participants to tell the months of the year in reverse order starting from December. They score 1 point if they can recall the whole year correctly. Therefore, the total score for the concentration test is 5 points.

The delayed recall test is recommended to be completed 5 minutes after the end of immediate memory test, and it requires the participants to recall as many words as possible

from the 10, or 5, word lists read to them earlier. The maximum score is 10, or 5, for the 10-word and 5-word lists respectively. The immediate memory and delayed recall scores were presented as percentages in the analysis, due to the variability in the ability of participants to complete either the 5 or 10 word lists.

2.3.3 Neurological screening

Neurological screening involved passive cervical spine movement, movement of eyes side-to-side, up-and-down without head movement, finger to nose coordination test; and heel-to-toe gait along a 3 meter line (Figure 2).

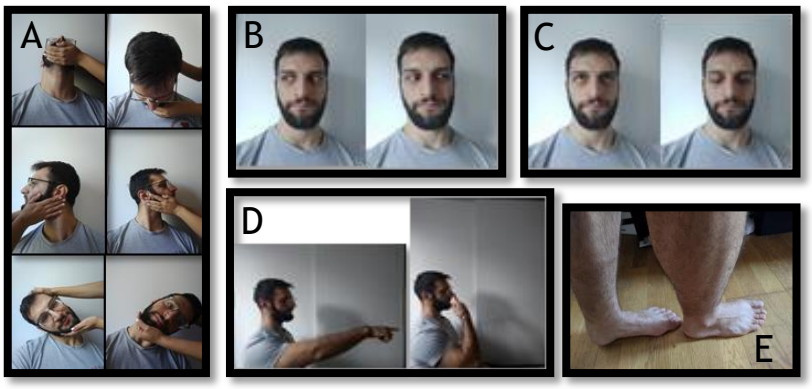

Figure 2: SCAT 5 neurological screening tests, including: A) passive cervical spine movement; B &C) side-to-side and up-down eye movement without moving the head; D) finger to nose coordination and E) heel-to-toe gait.

2.3.4 Balance examination (mBESS)

Participants are asked to maintain stability for 20 seconds on each of 3 different balance tests consisting of double leg stance, single leg stance on the non-dominant leg and tandem stance (heel-to-toe stance, as in Figure 2E) with non-dominant leg at the back. All balance tests are performed barefoot on a hard surface, with eyes closed and hands placed on the hips. For the single leg stance the participants have to hold the dominant leg in approximately 30 degrees of hip flexion and 45 degrees of knee flexion, which are measured with a goniometer. The investigator starts timing when the participant is set and closes his/her eyes. During each of the 20 second stances, the investigator is counting the number of times the participants move out of position, with each error counting as one point. The maximum amount of error points for each stance is 10 and the total balance test score is the sum of all errors from the three stances with a maximum of 30 errors. When participants move out position, the stopwatch is paused and the participants are instructed

to quickly assume the testing position again and once the participant is set the stopwatch resumes counting.

During analysis the double leg stance was excluded because the mean of both contact and non-contact sport group was 0 errors.

2.4 Electromyography

All measures were taken with the participants sitting on an isokinetic dynamometer (Kin-Com, Chattecx Corp, Chattanooga Group Inc., Tennessee) with their non-dominant leg positioned on the ankle pad of a calibrated lever arm and secured with the strap provided. The participants' knee angle was set at 60° (0° being fully extended leg) with the axis of rotation of the lever arm aligned with their lateral femoral condyle (Di Virgilio et al., 2016). The participant was stabilized on the dynamometer with shoulder, waist and thigh straps.

Before placing the electrodes, the area of skin over the rectus femoris (RF) and vastus lateralis (VL) was shaved and abraded according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines (Hermens et al., 2000). The EMG activity of both muscles was measured using Ag/AgCl ECG surface electrodes (Ambu, whitesensor WS, Denmark) with an inter-electrode distance of 2 cm. The response from RF and VL was recorded using a wireless EMG system (Biopac Systems, Inc. Goleta, CA, USA). Data were sampled at 2 kHz, and filtered with 500 Hz and 1 kHz, low and high band filters, respectively. The resulting signals were analysed using Acqknowledge software (Biopac Systems, Inc. Goleta, CA, USA).

Once the participants were set on the dynamometer and the electrodes placed on the target leg, they were asked to push at 50% of their perceived maximum for three times and then at 75% for three times to warm up the muscle. Then they performed three maximum voluntary contractions (MVCs) for 5 seconds each time, with verbal encouragement from the investigators. There was 1 minute rest between MVCs. The highest of the 3 MVC scores was selected and was used to calculate 20% of that MVC, which is used when measuring the active motor threshold (see section 2.5).

2.5 Transcranial magnetic stimulation (TMS)

The orientation of the coil on the head was such that the flow of current left the coil in an anterior-posterior direction and in turn, the induced intracranial current was in the opposite direction (Martin et al., 2008; Fischer and Orth., 2011).

Single pulse TMS was used to induce motor evoked potentials (MEPs) in VL and RF muscles of the non-dominant leg, in agreement with the single leg balance test used in SCAT 5; and the response was measured by electromyography (EMG) recordings. A magnetic stimulator (Magstim 2002 model, Magstim Company Ltd., Whitland, UK) attached to a 110 mm double-cone coil (Magstim Co. Ltd) was used to induce MEPs by applying single magnetic stimuli of 1 ms duration over the contralateral primary motor cortex. The optimal position of the coil over the motor cortex was determined by placing the coil laterally to the vertex and detecting the area where the largest MEP peak-to-peak amplitudes occurred (Goodall et al., 2009). This area was then marked on the scalp with a semi-permanent ink. The active motor threshold (aMT) was quantified based on the output of the stimulator, which goes from 0% to 100%. Therefore, the aMT for the VL and RF muscles was determined via increasing the stimulator intensity by 5% increments starting from 25%, while the participant was pushing at 20% MVC until distinct MEPs were visible. Subsequent stimulations were delivered at 130% of the aMT. For example, if distinct MEPs were observed at 40% of the stimulator intensity, then the subsequent stimulations would be at 52% (=1.3 * 40).

Corticospinal-silent period (cSP) was manually evaluated and measured as the duration of EMG silence starting from the onset of the stimulus artefact to the resumption of distinct, sustained EMG activity (Werhahn et al., 1999; Wilson et al., 1993). An example of cSP is shown in Figure 3. The participants were asked to perform three MVCs of 5 seconds duration each while a single TMS pulse was delivered over the pre-determined motor cortex area on the head. The 100% MVC was used to ensure that a large pool of motor units is recruited to see an effect, which is a commonly employed methodology in the literature (Goodall et al., 2009; 2012a, c). The TMS pulse was given at about 3 seconds into the MVC. The rest period between each MVC was 1 minute. When the TMS pulse was given, the target muscle would transiently lose strength, therefore participants were instructed to focus on pushing to their maximum when they feel the TMS pulse, until the 5 seconds are over. During each MVC the participant received verbal encouragement from the investigators.

The corticospinal-silent period was measured in milliseconds (ms), and the mean of the 3 corticospinal-silent periods was used for further analysis. We chose to examine corticospinal-silent period in the lower limbs because changes in the lower limbs are more functionally relevant to performance in American football since they directly relate to changes in balance.

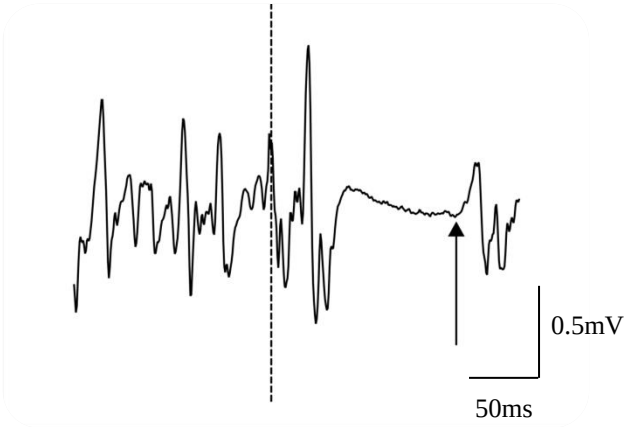

Figure 3: An example of cortico-silent period (cSP) from a single contact sport participant. The dotted vertical line indicates the signal from the TMS and the arrow indicates the resumption of distinct, continuous EMG activity. The duration of the cSP is measured as the time (ms) between the TMS pulse and the arrow. Y-axis: MEP amplitude (mV); X-axis: Time (ms).

2.6 Statistical Analyses

Graphpad Prism 6 statistical programme was used to perform descriptive statistical analysis. Statistical differences in corticospinal-silent period between contact and non-contact groups were analysed using unpaired t-tests. Analysis for statistical differences in SCAT 5 test scores between contact and non-contact groups was carried out using two-way repeated measures ANOVA using factors SCAT 5 tests (6 test scores) and groups (contact and non-contact sport groups). If significant differences were observed, Sidak's post hoc tests were used to further explore effects.

For all comparisons between contact and non-contact sports, we used the first week of data collected (corticospinal-silent period and SCAT 5 test scores) from contact sport participants, to match the conditions of the non-contact sport group. Effect sizes (ES) were calculated for the strength of differences in SCAT 5 test scores and corticosilent periods between contact and non-contact sport groups, using Cohen's d formula and were

quantified as follows: 0.2 = small; 0.5 = medium; 0.8 = large. The 95% lower and upper confidence intervals (CIs) were also calculated from the difference of the mean values. Day-to-day reproducibility and reliability analysis of the corticospinal-silent period and SCAT 5 test scores, between week 1 and 2 in contact sport participants, were measured using intra-class correlation coefficients (ICC) and coefficients of variation (CV), respectively. ICC values were defined as follow: ≤0.39 = poor; 0.40 – 0.59 = fair; 0.60 – 0.74 = good; 0.75 – 1.00 = excellent reproducibility, as outlined by Cicchetti (1994). The CV values were calculated using the formula: **(σ / μ)*100**; where **σ** is the standard deviation and **μ** is the mean of the sample.

We also used Pearson's correlation coefficient to examine the relationship between the severity of symptoms and corticospinal-silent period in contact sport participants. Statistical significance was set at $p \leq 0.05$ and data were expressed as mean ± standard deviation.

3. Results

3.1 Contact versus non-contact sport players

3.1.1 SCAT5

There were no significant differences between contact and non-contact sport groups for all SCAT5 test scores ($p > 0.05$; Table 1).

Table 1: Mean (± SD) SCAT 5 test scores are compared between contact and non-contact sports groups, with the respective effect sizes, adjusted p-values and the 95% CIs reported for each test. SD= standard deviation; CIs = confidence intervals.

	Contact sports	Non-contact sports			
	Mean (±SD)	Mean (±SD)	Effect size	Adjusted p-value	95% CI
SAC:					
Immediate memory score (%):	87 (±12)	90 (±6)	0.27	0.95	-13.42 to 9.04
Concentration score (/5):	4 (±1)	4 (±1)	0.28	>0.05	-10.99 to 11.47
mBESS (No. of errors)					
Single leg stance (/10)	2 (±3)	2 (±1)	0.36	0.63	-0.88 to 2.30
Tandem stance (/10)	0 (±1)	0 (±1)	0.15	>0.05	-1.53 to 1.65
Total mBESS errors (/30)	3 (±3)	2 (±2)	0.32	0.57	-0.83 to 2.36
Delayed recall					
Delayed recall score (%)	74 (±25)	82 (±17)	0.36	0.27	-18.88 to 3.58
Symptom severity score (/132)	4 (±6)	5 (±7)	0.18	0.61	-3.46 to 5.81

3.1.2 TMS

There were no significant differences in mean corticospinal-silent period between contact and non-contact sport participants ($p>0.05$) for the RF ($t= 0.56$; $p=0.58$; ES= 0.19; CI -10.68 to 6.10) and VL ($t=0.26$; $p=0.79$; ES= 0.09; CI -12.64 to 9.74) (Figure 4).

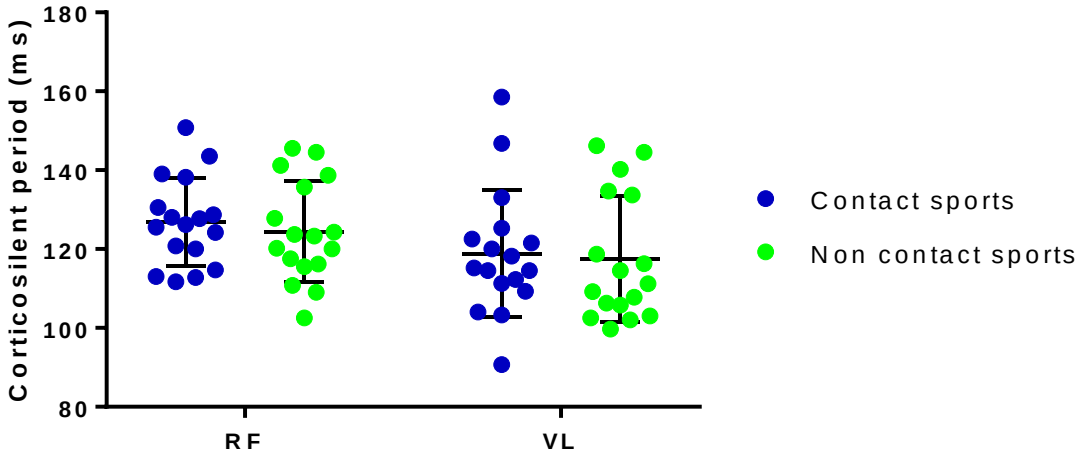

Figure 4: Scatter plot showing mean (long black, horizontal line) ± SD; and individual cortico-silent period values for the RF and VL muscles, for both contact and non-contact sports. RF: Rectus Femoris muscle, VL: vastus lateralis, SD: standard deviation**.**

3.2 Day-to-day reliability analysis

Day-to-day reproducibility (ICC) and reliability (CV) analysis of the corticospinal-silent period from RF and VL muscles between week 1 and 2 for contact sport participants, are shown in Table 2. Corticospinal-silent periods appeared to be consistent across the two weeks, with ICC analysis showing excellent reproducibility in both RF and VL muscles. Also, the dispersity of the mean corticospinal-silent periods between week 1 and week 2 was small, with VL showing higher dispersity than RF (CV (%); Table 2).

Table 2: Intra-class correlation coefficients (ICC) and coefficients of variation (CV) of corticospinal-silent periods between week 1 and week 2 test sessions, in contact sport players. LCL: lower confidence limit; UCL: upper confidence limit.

	RF		VL	
Corticospinal-silent period	ICC (LCL, UCL)	CV (%)	ICC (LCL, UCL)	CV (%)
	0.81 (0.54, 0.93)	4 ± 3	0.78 (0.47, 0.92)	6 ± 7

Day-to-day reproducibility and reliability analysis of SCAT 5 test scores between week 1 and 2 for contact sport participants, are shown in Table 3. Immediate memory score, concentration score and single leg stance had the poorest reproducibility among the SCAT

5 tests, followed by delayed recall score and total mBESS errors with fair reproducibility, and tandem stance score at the top with good reproducibility (ICC values; Table 3). Single leg stance and total mBESS errors test scores had the highest dispersity between week 1 and 2, followed by tandem stance and delayed recall scores with lower dispersity. Immediate memory and concentration scores had the lowest dispersity among the SCAT 5 tests (CV (%); Table 3). However, compared to corticospinal-silent period, SCAT 5 test scores presented poorer reproducibility (lower ICC values) and higher CVs (Tables 2 and 3).

Table 3: Intra-class correlation coefficients (ICC) and coefficient of variation (CV) of SCAT 5 test scores between week 1 and week 2 test sessions, in contact sport players. LCL: lower confidence limits, UCL: upper confidence limits.

SCAT 5 Tests	Immediate memory score	Concentration score	Delayed recall score	Single leg stance (/10)	Tandem stance (/10)	Total mBESS errors (/30)
ICC (LCL, UCL)	0.26 (-0.28, 067)	0.29 (-0.23, 0.68)	0.44 (-0.06, 0.76)	0.39 (-0.11, 0.74)	0.67 (0.27, 0.87)	0.54 (0.08, 0.81)
CV (%)	10 ± 9	12 ± 13	21 ± 23	66 ± 49	38 ± 63	56 ± 54

Further analysis was performed in the contact sports group, to determine whether there was a correlation between symptom severity scores reported and corticospinal-silent periods for both RF and VL (Figure 5). Linear regression analysis showed that symptom severity scores were not correlated with corticospinal-silent periods of RF (r= -0.26; p=0.35; CI -0.68 to 0.29) and VL (r= -0.05; p=0.87; CI -0.54 to 0.48).

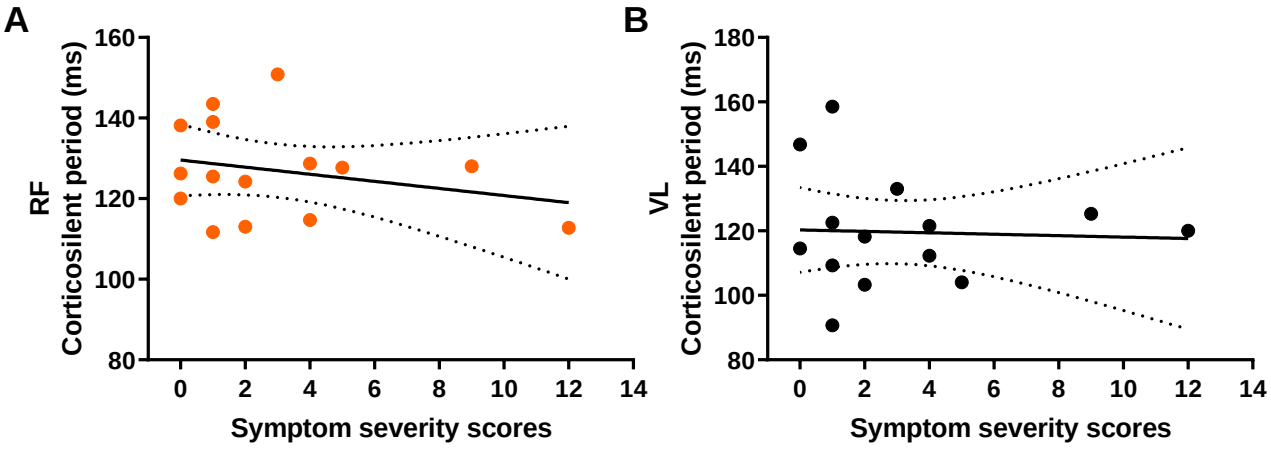

Figure 5: Linear regression scatter plots showing individual values of the correlation between cortico-silent periods and symptom severity scores in A) RF and B) VL of the contact sport group. The dotted curves represent the 95% CIs of the line of best fit (full line). RF: Rectus Femoris muscle, VL: vastus lateralis, CIs: confidence intervals.

4. Discussion

The present study explored the effect of subconcussive head impacts between contact and non-contact sport players on corticospinal-silent period (cSP) and SCAT 5, as well as the reliability and reproducibility of each measure in contact sport players.
In the first section of the study we observed no differences in SCAT 5 tests and in cSP for both RF and VL muscles, between contact and non-contact sport players. The second section of the study showed excellent reproducibility (ICC) for cSP, which is in agreement with a recent study that used the same methodology used in this study, to measure corticospinal-silent period (Di Virgilio et al., 2016). However, in comparison to the ICC of cSP, SCAT 5 test scores had lower reproducibility and therefore are less likely to have a good signal to noise ratio to detect neuropsychological changes caused by subconcussive head impacts.

The similarity of SCAT 5 test scores between contact and non-contact sport players observed in our study coincides with the general consensus in the literature that neuropsychological tests are not sensitive enough to detect any significant or consistent negative effects of subconcussive head impacts (Belanger et al., 2016; McAllister et al., 2012; Miller et al., 2007; Gysland et al., 2012; Diakogeorgiou et al., 2018). The sensitivity of SCAT 5 to detect subconcussive head trauma is limited due to its dependence on overt cognitive changes which may not be transparent enough to be detected following subconcussive head impacts. Another limitation of SCAT 5 is its effectiveness in accurately measuring cognition, specifically immediate and delayed memory, because both of those measures are affected by the athlete's level of attention. For example, if the athlete is not paying attention to the investigator reading the word list, then it is more likely that the athlete will not be able to repeat back as many words and as a result this will be translated as a poor memory score. However, the immediate memory test consists of three trials using the same word list, which gives the athlete the opportunity to improve his/her total score, and in turn the delayed memory score as well. Conversely, studies showed promising findings when using BESS on foam surface or galvanic vestibular stimulation tests, both of which presented vestibular system deficits that were significantly associated with cumulative subconcussive head impacts (Hwang et al., 2017; Miyashita et al., 2017)

One factor that might explain the lack of significant differences in TMS is the possibility that any effect of repetitive subconcussive head impacts on cSP dissipated within the 24-48 hrs after a game, or practice, when the trial sessions took place. In support

of the transient effect of repetitive subconcussive head impacts, a recent experimental study demonstrated a transient increase in cSP immediately following a bout of 20 headers, which returned to baseline 24 hours later (Di Virgilio et al., 2016). On the contrary, another study observed functional connectivity changes long after the end of the season in football players, which suggests a potential cumulative long-term effect of repetitive subconcussive head impacts (Abbas et al., 2015). Even though there are more neuroimaging studies presenting consistent evidence for the accumulative effects of repetitive subconcussive head impacts, there is diversity in the brain regions affected. For example, changes were observed in DLPFC, corpus callosum, amygdala, thalamus and cerebellum (Talavage et al., 2014; Bari et al., 2018; McAllister et al., 2014; Gong et al., 2018). In turn, the variability in the affected brain regions suggests that there is also diversity in the mechanisms responsible for the effects of repetitive subconcussive head impacts. As such, it is possible that some brain functions, such as the communication between brain and muscle as measured by the TMS, may not always be affected. This theory is also suggested by Chun et al. (2015) who found differences in the direction of FA between two football teams. The authors hypothesised that the difference in FA direction could be related to either axonal inflammation from higher frequency of low magnitude impacts, or damaged fiber structure from less frequent head impacts of higher magnitude (Chun et al., 2015).

It should also be noted, that the American football players in this study employed a style of play that revolved around trying to keep head to head contact to a minimum. It is possible that this style of play may have resulted in fewer subconcussive head impacts during the season, which may be a plausible explanation for the lack of significant differences in TMS between contact and non-contact sport players. However, it is difficult to quantify the number of subconcussive head impacts at this point since we did not use any head impact telemetry to measure head impact biomechanics. Future studies could combine TMS with head impact telemetry sensors to investigate whether there is a relationship with subconcussive head impacts.

The literature on serum biomarkers demonstrates that evidence for subconcussive head impacts is equivocal. For example, serum Tau was found to either decrease, or increase, over the course of the season but in both cases it was not associated with the frequency and magnitude of subconcussive head impacts (Kawata et al., 2018; Oliver et al., 2018). The inconsistency between studies may be because serum Tau is also transiently influenced by physical activity (Gill et al., 2017), which means that the role of physical

activity should be taken into account when interpreting the cumulative effect of subconcussive head impacts on serum biomarkers.

The dispersity around the mean cSP and SCAT 5 test scores between week 1 and week 2, allowed us to investigate the magnitude of change that would be detectable as a result of subconcussive head impacts. Even though the non-significant differences seen in cSP (RF = 1.6% and VL= 1.3%) were below the observed 4-6% CV (Table 2) threshold for detecting a true change, these differences were also very low to be considered a false negative error. In comparison to cSP, the variability of SCAT 5 test scores was higher and ranged from 10 % to 66 % (Table 3), which means there is a higher margin for missing a significant difference because of false negative error, which might be the case for the delayed recall score. There was a 10% difference in the delayed recall score between contact and non-contact sport players, but because of the 21 % CV, this difference was not classified as a true change. Therefore, based on the difference in CV values between cSP and SCAT 5 test scores, it is more likely to detect a real difference between contact and non-contact sport players using cSP than SCAT 5.

Evidence provided in our study and in Di Virgilio et al. (2016) showed TMS has high reproducibility and reliability in three different population groups, but we are unsure if it is sufficiently sensitive to detect small changes associated with accumulative effects of subconcussive head impacts. As such, another possible explanation for the lack of significant differences between contact and non-contact sport players can be assumed from Bari et al. (2018) who investigated both American football and soccer players. The authors found that football players exhibited neurometabolic changes that were significantly associated with cumulative head impacts exceeding 50g in force, whereas in soccer players the fewer subconcussive head impacts were not significantly associated with the neurometabolic changes (Bari et al., 2018). The lack of a significant association in soccer players was suggestive of a potential threshold on the amount of subconcussive head impact exposure before a deleterious effect becomes apparent. Therefore, in regards to our study, the lack of significant differences in cSP could be because repetitive subconcussive head impacts experienced by the American football players were possibly not deleterious enough to be detected by TMS. The statement above is also related to a limitation of our study regarding the athletes' history of play in terms of the level of competition and the length of participation in American football, which may be additional factors influencing the outcome of our results. For example, the senior players in the American football team have been playing for 4 years, which is the length of their bachelor's degree, and this is not

a long exposure to head impacts considering they were playing only 10 games per season. Whereas, the average playing experience for most of the NCAA football players ranges between 7- 9 years (Kawata et al., 2017; Joseph et al., 2018). Also the level of competition in the U.K. football league is lower compared to the U.S. NCAA football league where the athletes' main focus during their college time is to secure their scholarship and thus their training is at a higher level in order to be able to play more competitively.

In conclusion, this is the first study to demonstrate that American football players displayed similar electrophysiological and SCAT 5 characteristics as non-contact sport athletes. This finding is supported by our highly reliable and reproducible inter-day TMS data. Further study should seek to perform multiple electrophysiological measures in conjunction with head accelerometers over a number of successive seasons.

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SCAT5©

SPORT CONCUSSION ASSESSMENT TOOL — 5TH EDITION

DEVELOPED BY THE CONCUSSION IN SPORT GROUP

FOR USE BY MEDICAL PROFESSIONALS ONLY

supported by

Patient details

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date of Injury: _____ Time: _____

WHAT IS THE SCAT5?

The SCAT5 is a standardized tool for evaluating concussions designed for use by physicians and licensed healthcare professionals[1]. The SCAT5 cannot be performed correctly in less than 10 minutes.

If you are not a physician or licensed healthcare professional, please use the Concussion Recognition Tool 5 (CRT5). The SCAT5 is to be used for evaluating athletes aged 13 years and older. For children aged 12 years or younger, please use the Child SCAT5.

Preseason SCAT5 baseline testing can be useful for interpreting post-injury test scores, but is not required for that purpose. Detailed instructions for use of the SCAT5 are provided on page 7. Please read through these instructions carefully before testing the athlete. Brief verbal instructions for each test are given in italics. The only equipment required for the tester is a watch or timer.

Recognise and Remove

A head impact by either a direct blow or indirect transmission of force can be associated with a serious and potentially fatal brain injury. If there are significant concerns, including any of the red flags listed in Box 1, then activation of emergency procedures and urgent transport to the nearest hospital should be arranged.

Key points

- Any athlete with suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration. No athlete diagnosed with concussion should be returned to play on the day of injury.
- If an athlete is suspected of having a concussion and medical personnel are not immediately available, the athlete should be referred to a medical facility for urgent assessment.
- Athletes with suspected concussion should not drink alcohol, use recreational drugs and should not drive a motor vehicle until cleared to do so by a medical professional.
- Concussion signs and symptoms evolve over time and it is important to consider repeat evaluation in the assessment of concussion.
- The diagnosis of a concussion is a clinical judgment, made by a medical professional. The SCAT5 should NOT be used by itself to make, or exclude, the diagnosis of concussion. An athlete may have a concussion even if their SCAT5 is "normal".

Remember:

- The basic principles of first aid (danger, response, airway, breathing, circulation) should be followed.
- Do not attempt to move the athlete (other than that required for airway management) unless trained to do so.
- Assessment for a spinal cord injury is a critical part of the initial on-field assessment.
- Do not remove a helmet or any other equipment unless trained to do so safely.

Davis GA, *et al*. *Br J Sports Med* 2017;**0**:1-8. doi:10.1136/bjsports-2017-097506SCAT5

1

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date: _____

IMMEDIATE OR ON-FIELD ASSESSMENT

The following elements should be assessed for all athletes who are suspected of having a concussion prior to proceeding to the neurocognitive assessment and ideally should be done on-field after the first first aid / emergency care priorities are completed.

If any of the "Red Flags" or observable signs are noted after a direct or indirect blow to the head, the athlete should be immediately and safely removed from participation and evaluated by a physician or licensed healthcare professional.

Consideration of transportation to a medical facility should be at the discretion of the physician or licensed healthcare professional.

The GCS is important as a standard measure for all patients and can be done serially if necessary in the event of deterioration in conscious state. The Maddocks questions and cervical spine exam are critical steps of the immediate assessment; however, these do not need to be done serially.

STEP 1: RED FLAGS

RED FLAGS:

- Neck pain or tenderness
- Double vision
- Weakness or tingling/ burning in arms or legs
- Severe or increasing headache
- Seizure or convulsion
- Loss of consciousness
- Deteriorating conscious state
- Vomiting
- Increasingly restless, agitated or combative

STEP 2: OBSERVABLE SIGNS

Witnessed ☐ Observed on Video ☐

Lying motionless on the playing surface	Y	N
Balance / gait difficulties / motor incoordination: stumbling, slow / laboured movements	Y	N
Disorientation or confusion, or an inability to respond appropriately to questions	Y	N
Blank or vacant look	Y	N
Facial injury after head trauma	Y	N

STEP 3: MEMORY ASSESSMENT MADDOCKS QUESTIONS[2]

"I am going to ask you a few questions, please listen carefully and give your best effort. First, tell me what happened?"

_____

_____

Mark Y for correct answer / N for incorrect

What venue are we at today?	Y	N
Which half is it now?	Y	N
Who scored last in this match?	Y	N
What team did you play last week / game?	Y	N
Did your team win the last game?	Y	N

Note: Appropriate sport-specific questions may be substituted.

STEP 4: EXAMINATION GLASGOW COMA SCALE (GCS)[3]

Time of assessment			
Date of assessment			
Best eye response (E)			
No eye opening	1	1	1
Eye opening in response to pain	2	2	2
Eye opening to speech	3	3	3
Eyes opening spontaneously	4	4	4
Best verbal response (V)			
No verbal response	1	1	1
Incomprehensible sounds	2	2	2
Inappropriate words	3	3	3
Confused	4	4	4
Oriented	5	5	5
Best motor response (M)			
No motor response	1	1	1
Extension to pain	2	2	2
Abnormal flexion to pain	3	3	3
Flexion / Withdrawal to pain	4	4	4
Localizes to pain	5	5	5
Obeys commands	6	6	6
Glasgow Coma score (E + V + M)			

CERVICAL SPINE ASSESSMENT

Does the athlete report that their neck is pain free at rest?	Y	N
If there is NO neck pain at rest, does the athlete have a full range of ACTIVE pain free movement?	Y	N
Is the limb strength and sensation normal?	Y	N

In a patient who is not lucid or fully conscious, a cervical spine injury should be assumed until proven otherwise.

Davis GA, *et al*. *Br J Sports Med* 2017;**0**:1–8. doi:10.1136/bjsports-2017-097506SCAT5

OFFICE OR OFF-FIELD ASSESSMENT

Please note that the neurocognitive assessment should be done in a distraction-free environment with the athlete in a resting state.

STEP 1: ATHLETE BACKGROUND

Sport / team / school: _____

Date / time of injury: _____

Years of education completed: _____

Age: _____

Gender: M / F / Other

Dominant hand: left / neither / right

How many diagnosed concussions has the athlete had in the past?: _____

When was the most recent concussion?: _____

How long was the recovery (time to being cleared to play) from the most recent concussion?: _____(days)

Has the athlete ever been:

Hospitalized for a head injury?	Yes	No
Diagnosed / treated for headache disorder or migraines?	Yes	No
Diagnosed with a learning disability / dyslexia?	Yes	No
Diagnosed with ADD / ADHD?	Yes	No
Diagnosed with depression, anxiety or other psychiatric disorder?	Yes	No

Current medications? If yes, please list:

_____

_____

_____

_____

_____

_____

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date: _____

2

STEP 2: SYMPTOM EVALUATION

The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: ☐ Baseline ☐ Post-Injury

Please hand the form to the athlete

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6

Total number of symptoms:	of 22
Symptom severity score:	of 132
Do your symptoms get worse with physical activity?	Y N
Do your symptoms get worse with mental activity?	Y N
If 100% is feeling perfectly normal, what percent of normal do you feel?	

If not 100%, why?

_____

_____

_____

Please hand form back to examiner

Davis GA, *et al*. *Br J Sports Med* 2017;**0**:1–8. doi:10.1136/bjsports-2017-097506SCAT5

STEP 3: COGNITIVE SCREENING

Standardised Assessment of Concussion (SAC)[4]

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date: _____

ORIENTATION

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score		of 5

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List	Alternate 5 word lists					Score (of 5) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
					Immediate Memory Score			of 15
					Time that last trial was completed			

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
G	Finger Candle	Penny Paper	Blanket Sugar	Lemon Sandwich	Insect Wagon			
H	Baby Elbow	Monkey Apple	Perfume Carpet	Sunset Saddle	Iron Bubble			
I	Jacket Dollar	Arrow Honey	Pepper Mirror	Cotton Saddle	Movie Anchor			
					Immediate Memory Score			of 30
					Time that last trial was completed			

CONCENTRATION

DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
		Digits Score:			of 4

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan	0 1
Months Score	of 1
Concentration Total Score (Digits + Months)	of 5

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STEP 4: NEUROLOGICAL SCREEN

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

Can the patient read aloud (e.g. symptom check-list) and follow instructions without difficulty?	Y	N
Does the patient have a full range of pain-free PASSIVE cervical spine movement?	Y	N
Without moving their head or neck, can the patient look side-to-side and up-and-down without double vision?	Y	N
Can the patient perform the finger nose coordination test normally?	Y	N
Can the patient perform tandem gait normally?	Y	N

BALANCE EXAMINATION

Modified Balance Error Scoring System (mBESS) testing[5]

Which foot was tested (i.e. which is the non-dominant foot) ☐ Left ☐ Right

Testing surface (hard floor, field, etc.) _____

Footwear (shoes, barefoot, braces, tape, etc.) _____

Condition	Errors
Double leg stance	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at the back)	of 10
Total Errors	of 30

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date: _____

5

STEP 5: DELAYED RECALL:

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started _____

Please record each word correctly recalled. Total score equals number of words recalled.

_____

_____

_____

Total number of words recalled accurately: of 5 or of 10

6

STEP 6: DECISION

Domain	Date & time of assessment:		
Symptom number (of 22)			
Symptom severity score (of 132)			
Orientation (of 5)			
Immediate memory	of 15 of 30	of 15 of 30	of 15 of 30
Concentration (of 5)			
Neuro exam	Normal Abnormal	Normal Abnormal	Normal Abnormal
Balance errors (of 30)			
Delayed Recall	of 5 of 10	of 5 of 10	of 5 of 10

Date and time of injury: _____

If the athlete is known to you prior to their injury, are they different from their usual self?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**
(If different, describe why in the clinical notes section)

Concussion Diagnosed?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

If re-testing, has the athlete improved?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

I am a physician or licensed healthcare professional and I have personally administered or supervised the administration of this SCAT5.

Signature: _____

Name: _____

Title: _____

Registration number (if applicable): _____

Date: _____

SCORING ON THE SCAT5 SHOULD NOT BE USED AS A STAND-ALONE METHOD TO DIAGNOSE CONCUSSION, MEASURE RECOVERY OR MAKE DECISIONS ABOUT AN ATHLETE'S READINESS TO RETURN TO COMPETITION AFTER CONCUSSION.

Davis GA, *et al*. *Br J Sports Med* 2017;**0**:1–8. doi:10.1136/bjsports-2017-097506SCAT5

CLINICAL NOTES:

Name: _____

DOB: _____

Address: _____

ID number: _____

Examiner: _____

Date: _____

CONCUSSION INJURY ADVICE

(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, worsening headache, double vision or excessive drowsiness, please telephone your doctor or the nearest hospital emergency department immediately.

Other important points:

Initial rest: Limit physical activity to routine daily activities (avoid exercise, training, sports) and limit activities such as school, work, and screen time to a level that does not worsen symptoms.

1) Avoid alcohol

2) Avoid prescription or non-prescription drugs without medical supervision. Specifically:

   a) Avoid sleeping tablets

   b) Do not use aspirin, anti-inflammatory medication or stronger pain medications such as narcotics

3) Do not drive until cleared by a healthcare professional.

4) Return to play/sport requires clearance by a healthcare professional.

Clinic phone number: _____

Patient's name: _____

Date / time of injury: _____

Date / time of medical review: _____

Healthcare Provider: _____

Contact details or stamp

INSTRUCTIONS

Words in *Italics* throughout the SCAT5 are the instructions given to the athlete by the clinician

Symptom Scale

The time frame for symptoms should be based on the type of test being administered. At baseline it is advantageous to assess how an athlete "typically" feels whereas during the acute/post-acute stage it is best to ask how the athlete feels at the time of testing.

The symptom scale should be completed by the athlete, not by the examiner. In situations where the symptom scale is being completed after exercise, it should be done in a resting state, generally by approximating his/her resting heart rate.

For total number of symptoms, maximum possible is 22 except immediately post injury, if sleep item is omitted, which then creates a maximum of 21.

For Symptom severity score, add all scores in table, maximum possible is 22 x 6 = 132, except immediately post injury if sleep item is omitted, which then creates a maximum of 21x6=126.

Immediate Memory

The Immediate Memory component can be completed using the traditional 5-word per trial list or, optionally, using 10-words per trial. The literature suggests that the Immediate Memory has a notable ceiling effect when a 5-word list is used. In settings where this ceiling is prominent, the examiner may wish to make the task more difficult by incorporating two 5–word groups for a total of 10 words per trial. In this case, the maximum score per trial is 10 with a total trial maximum of 30.

Choose one of the word lists (either 5 or 10). Then perform 3 trials of immediate memory using this list.

Complete all 3 trials regardless of score on previous trials.

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order." The words must be read at a rate of one word per second.

Trials 2 & 3 MUST be completed regardless of score on trial 1 & 2.

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Score 1 pt. for each correct response. Total score equals sum across all 3 trials.
Do NOT inform the athlete that delayed recall will be tested.

Concentration

Digits backward

Choose one column of digits from lists A, B, C, D, E or F and administer those digits as follows:

Say: *"I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."*

Begin with first 3 digit string.

If correct, circle "Y" for correct and go to next string length. If incorrect, circle "N" for the first string length and read trial 2 in the same string length. One point possible for each string length. Stop after incorrect on both trials (2 N's) in a string length. The digits should be read at the rate of one per second.

Months in reverse order

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response

Modified Balance Error Scoring System (mBESS)[5] testing

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)[5]. A timing device is required for this testing.

Each of 20-second trial/stance is scored by counting the number of errors. The examiner will begin counting errors only after the athlete has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum number of errors for any single condition is 10. If the athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once the athlete is set. Athletes that are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

"I am now going to test your balance. Please take your shoes off (if applicable), roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] *Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Tandem Gait

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 metre line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object.

Finger to Nose

"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

References

1. McCrory et al. Consensus Statement On Concussion In Sport – The 5th International Conference On Concussion In Sport Held In Berlin, October 2016. British Journal of Sports Medicine 2017 (available at www.bjsm.bmj.com)
2. Maddocks, DL; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clinical Journal of Sport Medicine 1995; 5: 32-33
3. Jennett, B., Bond, M. Assessment of outcome after severe brain damage: a practical scale. Lancet 1975; i: 480-484
4. McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sport Medicine. 2001; 11: 176-181
5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30

CONCUSSION INFORMATION

Any athlete suspected of having a concussion should be removed from play and seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. The athlete should not be left alone and must go to a hospital at once if they experience:

- Worsening headache
- Drowsiness or inability to be awakened
- Inability to recognize people or places
- Repeated vomiting
- Unusual behaviour or confusion or irritable
- Seizures (arms and legs jerk uncontrollably)
- Weakness or numbness in arms or legs
- Unsteadiness on their feet.
- Slurred speech

Consult your physician or licensed healthcare professional after a suspected concussion. Remember, it is better to be safe.

Rest & Rehabilitation

After a concussion, the athlete should have physical rest and relative cognitive rest for a few days to allow their symptoms to improve. In most cases, after no more than a few days of rest, the athlete should gradually increase their daily activity level as long as their symptoms do not worsen. Once the athlete is able to complete their usual daily activities without concussion-related symptoms, the second step of the return to play/sport progression can be started. The athlete should not return to play/sport until their concussion-related symptoms have resolved and the athlete has successfully returned to full school/learning activities.

When returning to play/sport, the athlete should follow a stepwise, **medically managed exercise progression, with increasing amounts of exercise.** For example:

Graduated Return to Sport Strategy

Exercise step	Functional exercise at each step	Goal of each step
1. Symptom-limited activity	Daily activities that do not provoke symptoms.	Gradual reintroduction of work/school activities.
2. Light aerobic exercise	Walking or stationary cycling at slow to medium pace. No resistance training.	Increase heart rate.
3. Sport-specific exercise	Running or skating drills. No head impact activities.	Add movement.
4. Non-contact training drills	Harder training drills, e.g., passing drills. May start progressive resistance training.	Exercise, coordination, and increased thinking.
5. Full contact practice	Following medical clearance, participate in normal training activities.	Restore confidence and assess functional skills by coaching staff.
6. Return to play/sport	Normal game play.	

In this example, it would be typical to have 24 hours (or longer) for each step of the progression. If any symptoms worsen while exercising, the athlete should go back to the previous step. Resistance training should be added only in the later stages (Stage 3 or 4 at the earliest).

Written clearance should be provided by a healthcare professional before return to play/sport as directed by local laws and regulations.

Graduated Return to School Strategy

Concussion may affect the ability to learn at school. The athlete may need to miss a few days of school after a concussion. When going back to school, some athletes may need to go back gradually and may need to have some changes made to their schedule so that concussion symptoms do not get worse. If a particular activity makes symptoms worse, then the athlete should stop that activity and rest until symptoms get better. To make sure that the athlete can get back to school without problems, it is important that the healthcare provider, parents, caregivers and teachers talk to each other so that everyone knows what the plan is for the athlete to go back to school.

Note: If mental activity does not cause any symptoms, the athlete may be able to skip step 2 and return to school part-time before doing school activities at home first.

Mental Activity	Activity at each step	Goal of each step
1. Daily activities that do not give the athlete symptoms	Typical activities that the athlete does during the day as long as they do not increase symptoms (e.g. reading, texting, screen time). Start with 5-15 minutes at a time and gradually build up.	Gradual return to typical activities.
2. School activities	Homework, reading or other cognitive activities outside of the classroom.	Increase tolerance to cognitive work.
3. Return to school part-time	Gradual introduction of school-work. May need to start with a partial school day or with increased breaks during the day.	Increase academic activities.
4. Return to school full-time	Gradually progress school activities until a full day can be tolerated.	Return to full academic activities and catch up on missed work.

If the athlete continues to have symptoms with mental activity, some other accomodations that can help with return to school may include:

- Starting school later, only going for half days, or going only to certain classes
- More time to finish assignments/tests
- Quiet room to finish assignments/tests
- Not going to noisy areas like the cafeteria, assembly halls, sporting events, music class, shop class, etc.
- Taking lots of breaks during class, homework, tests
- No more than one exam/day
- Shorter assignments
- Repetition/memory cues
- Use of a student helper/tutor
- Reassurance from teachers that the child will be supported while getting better

The athlete should not go back to sports until they are back to school/learning, without symptoms getting significantly worse and no longer needing any changes to their schedule.

Davis GA, *et al*. *Br J Sports Med* 2017;**0**:1–8. doi:10.1136/bjsports-2017-097506SCAT5