The Effects of Sports-Related Concussion over One Season of Contact Sport on Neuropsychological Outcomes in School-Aged and Collegiate Athletes.

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Abstract

Objective: The objective of the current study was to ascertain whether concussions sustained over one season of contact sport adversely affects scores on neurocognitive outcome measures in a cohort of school-age and collegiate athletes, at both the group and individual level.

Methods: The current study is a within subjects repeated-measures design, with a sample size of 24 contact athletes recruited from two rugby teams ageing from 16 to 24 years. All athletes underwent full neuropsychological assessment on measures of verbal memory, visual memory, intellectual functioning (processing speed and verbal working memory), language and executive functioning, prior to the commencement of the sporting season, and subsequently a follow-up neuropsychological assessment post-season. Analysis was carried out at both the group and individual level.

Results: No decline in scores was found on neuropsychological outcome measures from pre- to post-season on the group level analysis. Six significant increases were found on the Logical Memory I, II and Recognition Trials (immediate and delayed verbal memory), ROCFT Immediate and Delay trials (immediate and delayed visual memory) and the WAIS-IV Coding subtest (processing speed). Regarding the individual analysis, two participants underwent significant decline (reliable change) on the ROCFT Recognition trial. Regression analysis did not reveal concussions sustained during the season as a significant predictor of neurocognitive change outcomes.

Conclusion: As the follow-up assessment was carried out post-season, the current study examined residual cognitive deficits, rather than deficits found in the acute stages of a concussion. The findings of the study suggest that concussions and head impacts over one sporting season did not adversely affect scores on neurocognitive outcome measures. However, the current study is not generalizable to females, all age brackets, nor is it generalizable to athletes sustaining concussions over longer periods of time. The current study was limited by a number of factors and it is recommended that future examinations of sports-related concussion and neurocognitive deficits are cognisant of these factors.

1.0 Introduction

1.1 Theoretical Background

Mild traumatic brain injury or concussion in sport and the management thereof, is a widespread and compelling challenge in sports-specialised medicine. The Rugby Union has been estimated to have one of the highest incidence of concussion in contact sport, with approximately 4-13.4 concussions per 1000 hours of play (McMillan et al., 2017). A study conducted by Rafferty et al. (2018) concluded that professional rugby players most likely will sustain a concussion after 25 matches, and also found that the combined international and club rugby rates of concussion were 21.5 per 1000 hours of play. Operationalising a clear-cut definition of concussion, to present, has proved problematic for practitioners and researchers alike. The most frequently and widely accepted definition is “a traumatically induced alteration in mental status that may or may not involve a loss of consciousness” (Kelly & Rosenberg, 1998). Most definitions of concussion place emphasis on the marked change of mental status, manifesting as transient confusion and loss of memory – the most identifiable attributes of a concussion. Recovery from a concussion is usually rapid and in most cases, ostensibly complete, despite the aetiology (Bigler, 2008).

According to Giza and Hovda (2001), the symptoms of concussion are predominantly related to acute dysfunction of metabolic processes. The neurons affected cause a potassium efflux almost immediately after the concussion takes place. This efflux of potassium results in the affected cells polarising, leading to glutamate release and in turn exacerbating the potassium efflux. Subsequently, hyper glycolysis occurs causing an increasing demand of energy in the brain. Other pathophysiological changes include a reduction of cerebral blood flow due to vasoconstriction, a consequence of an increase of extracellular calcium (Katayama, Becker, Tamura & Hovda, 1990). According to Lovell and Collins (1999), the primary symptoms of a concussion are as follows; headache, dizziness, confusion, amnesia, fatigue, drowsiness, low mood, emesis, nausea, photophobia, phonophobia, difficulty sleeping, disorientation, problems with balance, irritability, numbness and concentration difficulties.

The aforementioned pathophysiological changes may not completely resolve for several weeks, increasing the players neurological vulnerability to second-impact (SIS) or post-concussion syndromes (PCS). SIS has the potential to occur if a player endures a secondary injury before symptoms of the primary injury have resolved completely (Saunders & Harbaugh, 1984). The secondary injury causes dys-autoregulation of the brain, subsequently resulting in potential brain stem failure, an increase in intracranial pressure, coma, and sometimes death. PCS is the term used for any symptoms from either an isolated episode of head injury or a history of many chronic head injuries, lasting for more than 2-3 weeks in an individual. However, PCS is not as severe as SIS. (Collins & Hawn, 2002).

The significant variations in presentation and cognitive profile of athletes following concussion make the detection and management of the injury quite difficult and complex. Self-reporting of injury carried out by the athletes cannot be entirely entrusted and therefore a large burden falls on the management and clinicians. Elbin and Covassin (2010) recommend a multifaceted approach with regard to detection and management, consisting of a neuropsychological assessment prior to the sports season commencing which can be referred to as a baseline cognitive profile as well as post-injury testing. It has been reported that athletes may tend to minimise the severity of their injury due to fears of being withdrawn from a game or permanently demoted and subsequently, concussions remain unreported and untreated (Covassin & Elbin, 2010).

The existing literature provides contradicting reports on the neuropsychological consequences of sports-related concussion. On the one hand, a number of prospective studies and meta-analyses have concluded that successful recovery from mild traumatic brain injury occurs in the days to weeks post sustaining the injury – and no permanent or residual deficits on neurocognitive testing are detected 3 months post mTBI (Iverson, 2010). In a recent study carried out by McMillan et al. (2017), long-term health outcomes following repeated concussion in Retired International Rugby Players (RIRP) were investigated. It was reported that within this cohort, a high number of repeated mTBI/concussions were recorded – the majority (n=92) of the RIRP reported experiencing a concussion whilst playing rugby. The mean number of concussions reported throughout the RIRPs careers' was 13.9 (SD=18.9). However, the study found no significant differences between the RIRP group and healthy controls on tests of neurocognitive functioning. Furthermore, no significant correlations were found between frequency of concussion and neurocognitive test scores (Rey Auditory Verbal Learning Test (RAVLT-Immediate Memory) (Rey, 1941), Grooved Pegboard (Psychomotor Speed) and the MoCA (Montreal Cognitive Assessment)) (McMillan et al., 2016). Relatively similar results were found by Echemendia et al. (2001), in which baseline neuropsychological test scores were compared with post-injury test scores. Significant results were yielded in injured athletes when compared to healthy controls at 2 hours and 48 hours post sustaining concussion – controls performed significantly better than injured athletes. No group differences were found when the athletes were tested at 1 week post-injury. Interestingly, at 1 month post-injury, there was a statistically significant difference found between injured athletes and controls, with injured athletes obtaining marginally higher results on one measure of verbal learning and memory (Hopkins Verbal Learning Test (HVLT)). The authors give two viable explanations for this finding. The first being the possibility of the occurrence of type I error, and the second, the injured athletes motivation to perform well on these tests due to either their intrinsically competitive nature or the possibility of a poor performance leading to exclusion from play. Due to this, Echemendia et al. (2001) highlight the integral role motivation plays in neuropsychological testing.

Contrasting with the aforementioned literature, the following studies have indeed found significant decreases on neuropsychological outcome measures after sports-related concussions. However, it was not clarified whether the decreases were short-term or persistent. Neuropsychological deficits and the course of recovery following sport-related concussion in collegiate athletes were examined by Guskiewicz, Ross and Marshall (2001). Significant differences were found between the control and contact groups on both the Trail-Making Test and the Digit Span Backward, at days 1, 3 and 5 post injury, but no significant decline was found between baseline and post-injury neurocognitive scores. However, no follow-up testing took place in the post-acute stage of injury, therefore no conclusion was made regarding residual neurocognitive deficits. Iverson, Gaetz, Lovell and Collins (2004) yielded congruous results in their study examining the cumulative effects of concussion in amateur athletes. It was found that multiply concussed athletes performed significantly lower than singly concussed athletes on measures of memory when tested 2 days post-injury. However, again, follow-up assessment was not carried out post-season so it is not clear whether memory decrements found were persistent.

Further, the cognitive effects of one season of contact sports on collegiate athletes was investigated by McAllister et al. (2012). The objective of the study was to determine whether repeated exposure to head impact had a negative effect on neurocognitive test scores. The findings of the study indicated that repetitive head impacts over a single season of contact sports did not have a short-term adverse effect on the athletes neurocognitive functioning. Furthermore, it was also suggestive that as no systematic differences were found between the athlete cohorts at baseline assessment at the group level, accumulated head impacts sustained prior to the baseline measurements at the beginning of the sports season are not associated with a decrease in neurocognitive performance. There were however two significant decreases found post-season on measures of reaction-time and attention. It was inferred from the results of this study that more extensive work is needed to ascertain whether the effects demonstrated are persistent or relatively short-term.

1.2 Research Questions

The objective of the current study is to answer one primary research question, examining the relationship between neurocognitive deficits and sport-related concussion over one rugby season. Based on the existing literature, the following research question was formulated;

Is there a relationship between sports-related concussion and neurocognitive deficits at post-season testing in young Irish rugby players?

The aforementioned research question was formulated on the basis that the majority of existing literature exploring sports-related concussion focuses on pre-season (baseline) testing versus post-injury testing, in the acute stage of a concussion. The literature, while providing contradicting results, generally reports that neurocognitive deficits found post-concussion resolve between 7-14 days after the injury is sustained and further research is needed in order to ascertain whether decrements found are short-term or long lasting. Therefore, the current study aims to explore the relationship between pre-season testing versus post-season testing, in the post-acute stages of potential sport-related concussion, to assess whether there are more lasting effects. The presence of residual neurocognitive deficits and the effects of concussion will be investigated by testing the following hypotheses:

Hypothesis 1: It is expected that there will not be a statistically significant decrease at the group level in test scores across all domains in neuropsychological tests carried out pre- and post-season.

Hypothesis 2: It is expected that concussions sustained during the sporting season will not have a significant effect on individual outcomes at post-season testing.

2.0 Methodology

2.1 Study Design

The design of the current study is a within subjects repeated-measures design, investigating the relationship between neurocognitive deficits and sports-related concussion, with measures taken at two time points pre-and post-rugby season, over a time period of 8-9 months.

2.2 Participants

The data for the study was drawn from two amateur rugby teams, between September 2015 (pre-season) to June 2016 (post-season). The participants were recruited by the Concussion Research Interest Group at Trinity College Dublin, in conjunction with St James' Hospital, Beaumont Hospital and Tallaght Hospital. Informed consent was obtained from each participant, and consent from a legal guardian was obtained for all participants under the age of 18 years. The participant group consisted of twenty four male athletes, with an age range of 17-26 years.

2.2.1 Inclusion Criteria

The inclusion criteria used for the current study is as follows: (a) participants must have completed both baseline (pre-season) neuropsychological assessment and follow-up neuropsychological assessment (post-season) (b) individuals must have participated in a full rugby season.

2.2.2 Exclusion Criteria

The following exclusion criteria was applied to the current study: (a) the participants must not have experienced a vascular event or neurological injury prior to beginning the study and (b) participants were not included if they were non-responders at the post-season follow-up assessment (T2).

2.3 Materials

2.3.1 Demographics

Demographic data including age, gender, handedness, previous personal and family medical history was collected from the participants by means of an intake interview prior to completing the baseline neuropsychological assessment.

2.3.2 Neurocognition

Neuropsychological assessment was carried out before the commencement of the rugby season in September 2015, and post-season from May-June 2016, by trained assistant psychologists from the Department of Psychology, Beaumont Hospital. The number of concussions sustained by each participant was obtained at T2 using the Sports Concussion Assessment Tool (SCAT3). The neuropsychological assessments consisted of the following tests;

Table 1. Details of the Neuropsychological Tests Employed

Neurocognitive Domain	**Subtests**
1. Premorbid Functioning	-Test of Premorbid Functioning (ToPF-UK)
2. Verbal Memory	
➢ Immediate	-Rey Auditory Verbal Learning Test (RAVLT) (Lezak, 1995); List Learning 1-5. -Wechsler Memory Scale Fourth Edition (WMS-IV) (Wechsler, 2009); Logical Memory I.
➢ Delayed	-RAVLT; List Recall (Lezak, 1995) -RAVLT; List Recognition (Lezak, 1995) -WMS IV; Logical Memory II Recall (Wechsler, 2009).
3. Visual Memory	
➢ Immediate	-Rey-Osterrieth Complex Figure Test (ROCFT); Immediate Recall (Meyers & Meyers, 1995).
➢ Delayed	-ROCFT; Delayed Recall (Meyers & Meyers, 1995) -ROCFT; Recognition (Meyers & Meyers, 1995).
4. Intellectual Functioning	
➢ Verbal Comprehension	-Wechsler Abbreviated Scale of Intelligence Second Edition (WASI-II); Vocabulary (Wechsler, 2011)
➢ Perceptual Reasoning	-WASI-II; Matrix Reasoning (Wechsler, 2011)

➢ Verbal Working Memory	-Wechler Adult Intelligence Scale Fourth Edition (WAIS-IV); Digit Span (Wechsler, 2008)
➢ Processing Speed	-WAIS-IV; Coding (Wechsler, 2008)
5. Executive Functioning	
➢ Phonemic Fluency	-Delis-Kaplan Executive Functioning Systems (DKEFS); Letter Fluency (Delis, Kaplan & Kramer, 2001)
➢ Semantic Fluency	-DKEFS; Category Fluency (Delis, Kaplan & Kramer, 2001).
6. Language	
➢ Confrontational Word Naming	-Boston Naming Test (BNT); 30 item short-form (Kaplan, Goodglass & Weintraub, 1983).
7. Concussion Assessment	-Sports Concussion Assessment Tool (SCAT3) (2013) -King Devick Test (1983)

2.4 Procedures

2.4.1 Ethical Approval

Ethical approval for the current study was received from Trinity College Dublin, St James' Hospital, Beaumont Hospital and Tallaght Hospital, in April 2015.

2.4.2 The Concussion Research Interest Group

As part of the larger research programme (the CRIG), participants underwent a number of examinations and tests, which consisted of;

1. 3-Tesla magnetic resonance imaging, including fMRI.
2. Neuropsychological assessment (pre-and post-season)
3. Visual Eye-tracking and ocular Micro-tremor analysis (pre- and post-season).
4. Blood levels of products of blood brain barrier disruption analysis pre- and post-season.
5. Retinal vein tortuosity/aberrant vascular patterning analysis.
6. Genetic Screening - DNA samples analysis in order to examine genetic susceptibility to brain injury.
7. Rehabilitation and prognostic assessment.

The current study utilises data from the neuropsychological assessments for analysis and interpretation.

2.4.3 Statistical Analysis

All neuropsychological tests were scored in accordance with their manual guidelines and corrected in terms of gender and age, where deemed necessary. The scores were obtained as Raw Scores, Percentile Scores and Standard scores and were converted into Z-scores for analysis in SPSS. Alternate forms of the tests were utilised where available, however were not available for WMS-IV Logical Memory I, II, Recognition, DKEFS Letter and Category Fluency, WAIS-IV Digit Span and Coding. Power of the sample was calculated using SPSS. The RCI calculations were carried out utilising standardised Z-scores obtained from the raw test scores. As the control group was not tested at T2, the Standard error of the difference – the difference between the means of two samples - could not be calculated from this data, but was obtained from a number of sources; The S_{diff} for the ROCFT and WAIS-IV subtests were calculated using data that was extracted from the test manuals. The S_{diff} for the WMS-IV Logical Memory subtests was also found in the user's manual. The DKEFS S_{diff} was extracted from a textbook by Scott (2011) and the S_{diff} for the RAVLT was calculated using data obtained from the RAVLT manual. Finally, the Sdiff for the BNT was taken from Sachs et al.'s (2012) study on reliable change on the BNT.

To calculate the effect sizes of the differences, the effect size *d* was calculated using Cohen's formula;

$$d = (M_2 – M_1)/ SD_{pooled} \quad \text{(Cohen, 1988).}$$

When the assumptions for Cohen's d were violated, the effect size *r* was calculated using the formula;

$$r = Z / \sqrt{Nx + Ny} \quad \text{(Pallant, 2007).}$$

To indicate the effect size range, Cohen's criteria was utilised, where 0.1 = small effect size, 0.3 = medium effect size and 0.5 = large effect size (Cohen, 1988).

The hypotheses were statistically analysed using the following tests;

Hypothesis 1: Analyses involved within group comparisons between pre and post-season measures of general intellectual ability, memory, executive functioning, visuospatial perception and language. All of the continuous variables were tested for the presence of outliers and normal distribution using the Shapiro-Wilk test for samples of a small/medium size (up to n=2000). Statistical analysis was carried out using a Paired Samples T-test to test Hypothesis 1, with significance represented by a p-value of ≤ 0.05. As some of the data from specific variables was not normally distributed (RAVLT 5, RAVLT Delay, ROCFT Delay, ROCFT Recognition, and Logical Memory Recognition) the Wilcoxon Signed Rank Test was used. Effect sizes of the differences were calculated for each of the outcome measures using Cohen's *d* and *r* (Cohen, 1988; Pallant, 1997).

Hypothesis 2: To test Hypothesis 2, the Reliable Change Index (z) was employed in order to examine case-by-case whether statistically significant changes occurred from pre- to post-season. The RCI is primarily concerned with examining change on an intra-individual basis, rather than change occurring on a group level, by taking into account the expected change over time or standardised psychometric variance. The lower and upper cut-off figures were set as (-1.96) and (1.96). If the result obtained from the analysis is lower than the desired z-score significance level (-1.96; $p \leq 0.05$), then the change can be considered to be beyond chance variance and constitutes a statistically significant decline.

The formula utilised for the RCI is as follows;

$$\frac{\textit{T2(Post-Season) - T1(Pre-Season)}}{\textit{Standard Error of the Difference } (S_{diff})}$$ (Jacobson & Truax, 1991)

Hypothesis 2 was then further analysed using a Binomial Logistic Regression in order to assess the impact of concussions sustained during the sporting season on whether participants would undergo significant decline on neurocognitive outcomes at post-season testing (analysed using the RCI). The dependant (outcome) variable was the RCI calculation and only RCIs on tests that showed significant decline were selected for further analysis.

3.0 Results

3.1 Demographic Information

Table 2 shows the demographic data of the participants. The sample consisted of 100% male athletes (n=24) , with a mean age of 18.3 years (range 16-26). Handedness was specified by the participants and 4.2% of the sample were left-handed (n=1). History of concussion prior to the commencement of the season was recorded as was the number of concussions sustained during the season.

Table 2.

Demographic and Clinical Characteristics of the Study Sample

		Sample N=24
Age in years (Mean; SD)	18.8; 2.6	Range 16-26
Gender (N)	Male =24 (100%)	
Handedness	Right = 23 (95.8% of players)	
	Left = 1 (4.2% of players)	
Mean FSIQ	Z= -.16 (SD= 0.65)	
Concussion History (pre)	11 (n=9, 37.5% of players)	
	Mean= 0.46; SD = 0.66	
Concussions During Season	15 (n=7, 29% of players)	
	Mean = 0.68; SD = 1.21	
Hospitalisation due to Concussion	0	
Presence of Dyslexia	n=3 (12.5% of sample)	

3.2 Neurocognitive Assessment Results

An overview of the group analysis of the neuropsychological assessment is presented in Table 2. The number of participants involved in the analysis of each measure is indicated with N, and participants that did not complete the post-season assessment were excluded.

3.2.1 Hypothesis 1: It is expected that there will not be a statistically significant decrease in test scores at the group level across all domains in neuropsychological tests carried out pre- and post-season.

Group Level Analysis

The results of the group level analysis can be seen compiled in Table 4.

Verbal Memory

The paired samples t-test revealed a statistically significant increase on a measure of immediate verbal memory (Logical Memory I subtest; WMS-IV) with a medium effect size (p-value $\leq$ 0.002, effect size: 0.38). Another statistically significant increase was found on a delayed verbal memory (Logical Memory II subtest; WMS-IV), with a large effect (p-value $\leq$ 0.009, effect size: 0.52). Finally, a third statistically significant increase was found on a measure of verbal recognition memory z=-2.04, p$\leq$0.05. (Logical Memory Recognition trial, WMS-IV), with a medium effect (r=0.29). All other measures of verbal memory and verbal working memory remained relatively stable, with no statistically significant decreases in scores taking place.

Visual Memory

Visual memory was again analysed using the paired samples t-test or the non-parametric equivalent and two statistically significant increases were found in this analysis. The first significant increase was on the ROCFT Immediate trial, with a large effect size (p-value $\leq$ 0.027; effect size: 0.56). The second significant increase was found on the ROCFT Delay trial z=-2.13, p $\leq$0.05, with a medium effect (r=0.31).

Processing Speed

Group-level analyses revealed a statistically significant increase from pre- to post-season on the WAIS-IV Coding subtest, with a large effect size (p-value $\leq$ 0.008; effect size: 0.56).

Executive Functioning

No statistically significant change was found at the group level over the course of the sports season on measures of executive functioning.

Language

Finally, on measures of language, no statistically significant results were yielded from the group level analysis, and the group mean remained relatively stable over the duration of the season.

Post-hoc power analysis was carried out utilising the G*power software (Erdfelder, Faul and Buchner, 1996) and can be seen in Table 3 (range 0.05 to 0.81).

*Table 3: Results of G*Power analysis*

Outcome Measure	**Logical Memory I**	**Logical Memory II**	**Logical Memory Rec.**	**ROCFT Imm.**	**ROCFT Delay**	**WAIS Coding**	**DKEFS Semantic**	**DKEFS Phonemic**
Calculated Power	0.65	0.74	0.81	0.75	0.59	0.72	0.17	0.30

Outcome Measure	**ROCFT Rec.**	**RAVLT 1**	**RAVLT 5**	**RAVLT Learning**	**RAVLT Rec.**	**WAIS Digit Span**	**BNT**
Calculated Power	0.61	0.05	0.26	0.06	0.45	0.32	0.38

Note: Cohen's (1988) recommended level of power is $\leq$0.8.

As there were no statistically significant decreases found on outcome measures on the group level analysis, it can be said that the data supports hypothesis 1.

Table 4: Averaged Within Subjects Comparisons; Pre- and Post-Season Assessment (z-scores)

Neurocognitive Domain	Outcome Measure	Pre-Season Assessment (N; Mean(SD))	Post-Season Assessment (N; Mean(SD))	P-Value (2-tailed)	Effect Size
Immediate Verbal Memory	RAVLT 1	22; 0.13 (1.08)	22; 0.11 (1.55)	*p=0.959*	0.01
	RAVLT 5	24; 0.86 (1.09)	24; 0.52 (1.29)	[A]*p=0.161*	0.20
	RAVLT Learning	22; 0.36 (1.18)	22; 0.25 (1.71)	*p=0.758*	0.07
	Logical Memory I	24; 0.25 (0.79)	24; 0.53 (0.68)	*p=0.002*	0.38
Delayed Verbal Memory	RAVLT Delay	24; 0.39 (1.50)	23; 0.18 (1.79)	[A]*p=0.365*	0.13
	RAVLT Recognition	23; 0.42 (0.65)	24;-0.04 (1.36)	*p=0.100*	0.39
	Logical Memory II	24;-0.10 (0.99)	24; 0.39 (0.71)	*p=0.009*	0.52
	Logical Memory Rec.	24; 0.00 (0.82)	24; 0.43 (0.46)	[A]*p=0.041*	0.29
Imm. Visual Memory	ROCFT Immediate	22; 0.43 (1.14)	22; 1.06 (1.11)	*p=0.027*	0.56
Delayed Visual Memory	ROCFT Delay	24; 0.42 (1.09)	24; 0.94 (1.14)	[A]*p=0.032*	0.31
	ROCFT Recognition	24;-0.12 (0.84)	24;-0.88 (1.83)	[A]*p=0.190*	0.19
Verbal Working Memory	Digit Span	22; 0.27 (0.75)	22; 0.53 (0.87)	*p=0.084*	0.32
Processing Speed	Coding	22;-0.14 (0.61)	22; 0.30 (0.93)	*p=0.008*	0.56
Executive Function	Phonemic Fluency	22; 0.29 (1.16)	22; 0.62 (0.95)	*p=0.096*	0.31
	Semantic Fluency	22; 1.08 (0.87)	22; 0.89 (0.92)	*p=0.297*	0.21
Language	BNT	22; 0.10 (0.52)	22;-0.12 (0.69)	*p=0.144*	0.36

Note: $p \leq 0.05$ [A]*Non-parametric*

Table 5: Individual Reliable Change Indices

ID CODE	Concussions Pre	Post	ROCFT Immediate	ROCFT Delay	ROCFT Recognition	WMS LM1	WMS LM2	WMS LM Recognition	RAVLT A1	RAVLT A5
003	1	3	0.45	0.28	-0.32	1.93	**2.47**	**1.97**	0.64	-0.83
004	0	0	-0.06	-0.22	0.32	0.97	1.65	**2.27**	0.31	0.42
005	1	1	0.11	-0.11	0.64	0.97	0.83	-0.76	0.31	0.00
006	1	1	0.28	0.22	-0.32	0.48	0.42	0.45	-0.63	-1.24
007	0	0	0.00	0.11	-1.27	0.49	0.83	1.21	-1.27	0.42
008	0	0	-0.22	-0.28	0.64	1.45	1.23	1.21	0.64	-0.83
009	1	1	0.00	-0.17	0.64	-0.49	0.42	-0.76	-0.64	-0.42
011	0	0	0.06	-0.17	-0.53	0.00	0.00	-1.21	0.06	0.42
012	0	0	0.11	0.06	-0.96	0.48	-0.42	0.00	-1.27	-0.83
013	0	0	0.45	0.27	-0.96	1.94	1.23	0.45	-0.32	0.00
015	1	0	-0.11	0.23	0.32	0.00	0.42	0.00	1.58	0.00
016	1	0	0.22	-0.06	**-2.55**	0.97	0.81	1.21	0.00	-1.25
017	0	0	0.45	0.11	-0.32	0.00	1.23	1.21	-0.32	0.00
019	0	0	0.00	-0.06	-0.64	0.00	-0.81	-0.45	-0.64	0.00
020	2	2	-0.22	-0.01	0.07	-1.45	0.41	1.52	0.32	0.00
030	0	3	0.84	0.76	0.00	0.00	0.00	0.00	-0.64	-0.41
023	2	4	-0.14	0.42	**-2.39**	0.00	-0.83	-0.76	-0.31	0.44
041	0	0	0.51	0.00	-1.74	0.97	-0.46	0.00	-1.22	0.00
043	0	0	0.37	0.13	-0.35	**2.41**	0.62	0.76	-0.41	-0.27
040	0	0	0.47	0.74	0.35	-1.45	1.69	**3.64**	**2.80**	0.54
044	0	0	0.07	0.21	0.00	-0.48	0.00	1.06	-0.36	0.27
047	0	0	0.45	0.50	1.14	0.00	-0.04	0.00	1.22	-0.27
049	0	0	-0.62	0.24	0.70	-0.46	**3.67**	**4.55**	-0.41	-0.54
050	0	0	0.34	0.20	-1.04	0.97	-0.86	-1.82	0.00	0.00

Figures in bold indicate significant (reliable) change ($p \leq \pm 1.96$)

Table 5 continued

ID CODE	Concussions Pre	Post	RAVLT Learning	RAVLT Recall	RAVLT Recognition	WAIS Digit Span	WAIS Coding	DKEFS Phonemic	DKEFS Semantic	BNT
003	1	3	0.20	0.00	-0.43	1.16	0.41	1.16	-0.48	0.00
004	0	0	0.20	0.60	0.00	1.17	0.21	-0.29	-0.16	-0.27
005	1	1	0.03	-0.60	0.00	-0.29		-0.29	-0.16	-0.14
006	1	1	-0.43	-1.81	-0.21	0.00	0.00	0.00	0.16	-0.13
007	0	0	-0.33	0.30	0.00	-0.29	0.21	-0.43	0.00	-0.27
008	0	0	0.27	1.80		-0.58	0.63	0.29	-0.63	-0.14
009	1	1	-0.47	0.00	0.00	-0.58	0.83	-0.14	0.00	0.00
011	0	0	0.10	0.30	0.00	0.00	0.21	0.43	-0.32	0.00
012	0	0	-0.57	-0.90	0.00	0.29	0.21	0.29	-0.32	-0.27
013	1	0	0.00	-0.60	0.00	0.00	0.42	0.58	-0.16	-0.14
015	1	0	0.33	0.00	0.00	0.29	0.63	0.29	-0.32	-0.02
016	1	0	-0.23	-1.20	0.04	0.00	0.42	-0.29	0.32	0.39
017	0	0	-0.03	-0.60	0.21	-0.87	0.00	0.29	-0.16	0.13
019	0	0	-0.07		0.00	0.58	-0.42	0.29	0.16	-0.54
020	2	2	-0.07	-1.20	-1.07	0.30	0.21	0.15	0.32	0.27
030	0	3	-0.43	0.60	-0.21	0.00	-0.41	0.14	-0.16	-0.66
023	2	4	-0.33	0.58	0.00	-0.87	0.00	-0.43	0.16	-0.27
041	0	0	-0.20	-0.63	0.00	0.30	0.00	0.15	-0.48	0.14
043	0	0	-0.05	-0.21	0.00	1.16	1.66	0.58	0.49	-0.14
040	0	0	0.37	0.43	-0.09	0.30	-0.21	0.30	-0.32	0.14
044	0	0	0.44	0.39	-0.09	0.57	0.42	0.15	0.79	0.12
047	0	0	0.47	0.00	0.00	0.00	0.21	0.27	0.32	-0.27
049	0	0	-0.17	0.46	-0.09	0.57	0.43	-0.43	-0.50	0.00
050	0	0	0.10	-0.21	-0.09	0.87	0.84	-0.29	-0.64	0.13

3.2.2 Hypothesis 2: It is expected that concussions sustained during the sporting season will not have a significant effect on individual outcomes at post-season testing.

Individual Level Analysis

The results of the individual level analysis calculated using the Reliable Change Index can be seen in Table 5.

The individual level analysis revealed few significant findings, however for the most part, the results were consistent with the group level analysis. Therefore, hypothesis two is mostly supported by the data. On scrutinising the data, individuals were found to have undergone few significant decreases across outcome measures. The highest amount of concussions reported by a participant during the season was four, with two concussions reported prior to the commencement of the rugby season. This participant underwent one significant decrease on the ROCFT Recognition trial. The second participant who underwent a significant decline on the ROCFT Recognition trial reported sustaining one concussion prior to the season, but no concussions during the sporting season. The outcome measure that had the highest number of significant decreases was the ROCFT Recognition subtest (2 out of 24 participants).

The data was then further analysed using a Binomial Logistic Regression, in order to assess the impact of concussions sustained on whether participants underwent significant decline at post-season testing, on the ROCFT Recognition trial. The logistic regression model failed to predict the outcome variable and was not statistically significant $X^2(1) = 2.28$, $p = .131$. The model explained 20.7% (Nagelkerke R^2) of the variance in significant decline at post-season testing. The predictor variable – concussions sustained during the sporting season, was not statistically significant. Whether concussions were sustained over the duration of the season was not associated with undergoing significant decline in performance on neurocognitive outcomes. Table 6 shows the results of the regression analysis.

Table 6: Binomial Logistic Regression prediction of significant decline in neurocognitive outcomes (ROCFT Recognition trial only).

						95% CI for Odds Ratio	
	B	SE	Wald	*Df*	*p*	Lower	Upper
Concussions (during season)	.773	.512	2.28	1	.131	.795	5.91

$p \leq 0.05$

4.0 Discussion

The current study had two primary aims. The first was to examine the presence of residual neurocognitive deficits among young athletes subsequent to one season of rugby at the group level, and the second aim was to examine whether significant individual differences in neurocognitive deficits from pre- to post-season, expressed by the Reliable Change Index, were potentially related to concussions sustained during the sporting season.

4.1 Hypothesis 1: Group Level Analysis

The first hypothesis stated that there would be no significant decreases in neurocognitive test scores found from pre- to post-season. Indeed, at the group level, a significant decline in neurocognitive test scores was not found among the participants, and scores on the majority of outcome measures remained relatively stable. There was however, statistically significant increases found on measures of verbal memory, visual memory and processing speed.

The aforementioned findings can be said to be somewhat consistent with the existing literature. As documented by Iverson (2010), a number of prospective studies and meta-analyses concluded that recovery from concussion-induced neurocognitive deficits takes place in the days and weeks following the injury – with no persistent or residual deficits recorded 3 months post-injury. However, as the specifics of the athlete's concussions – date, time, severity and associated neurocognitive deficits – were not recorded in the present study, it is not possible to say when the athletes' symptoms, if any, completely resolved. Barth et al. (1989) also concluded that neurocognitive deficits observed immediately post-injury were found to be completely resolved at a maximum time period of 10 days after the concussion was sustained.

With regard to the significant increases found on measures of verbal memory, visual memory and processing speed – these findings are only partly in line with existing literature. While Echemendia et al.'s (2001) study found there was a significant improvement in the injured athlete's performance when compared to healthy controls on the Hopkins Verbal Learning Test, this finding was on a measure of verbal learning and memory, not processing speed nor immediate visual memory. Furthermore, the existing literature reports that processing speed is a neurocognitive function most vulnerable to decrement following sports-related concussion (Covassin and Elbin, 2010). This may suggest that learning took place over the two time-points and the change observed is due to practice effects. Another explanation for the improvements in neurocognitive scores is motivation; the motivation of athletes to perform well at post-season testing, as failure to perform well could have an impact on return-to-play decisions, as well as having an intrinsically motivated and competitive nature (Echemendia et al., 2001).

4.2 Hypothesis 2: Individual Analysis

Individual analysis revealed similar results to the group level analysis. It was found that two participants underwent significant decreases on one outcome measure – the ROCFT recognition trial. No significant degradation in scores were found on the majority of outcome measures. A Binomial Logistic Regression was then carried out in order to assess whether concussions sustained during the season had an impact on cognitive change scores. This analysis did not find concussions sustained as a significant predictor of degradation in scores on the ROCFT Recognition trial at post-season assessment. This finding is in line with existing literature, as previously mentioned, neurocognitive symptoms associated with concussion generally resolve between 2 and 14 days post-injury, and the current study tested athletes post-season, in the post-acute stages of concussive injury.

The findings from the analysis of hypothesis 1 and 2 are relatively concordant with one another. No significant degradations were found in the group analysis of hypothesis 1, and only two participants underwent significant decline on one outcome variable in the individual analysis.

4.3 Limitations of the Study

The current study was limited by a number of factors. It is worth mentioning a caveat when conducting analysis was indeed the sample size of the study. Although two rugby teams were recruited for the current study, the specific exclusion criteria such as history of head trauma or neurological insult and non-responders at post-season neuropsychological assessment resulted in a modest sample size of 24 athletes being included in the formal analysis. A post-hoc power analysis revealed that the statistical power of only one of the statistical tests (WMS-IV Logical Memory Recognition subtest) was found to be above the recommended level of 0.8 (Cohen, 1988, 1992), therefore, there was above an 80% chance of the detection of an effect if one existed in the study sample. However, for the remainder of the tests carried out, the power was found to be below the recommended level of 0.8, which was insufficient.

Having clarified the power of the sample, a second limitation of the study was the lack of control data. As there was no control data at Time 2, it was not possible to compare whether results found within the cohort were natural to the specific demographic of the participants or occurred due to the presence of concussion, the occurrence of a full academic year, participation in contact sport or other extraneous variables. Therefore, a repeated measures ANOVA could not be carried out and the primary analysis was carried out using a Paired Samples T-test or non-parametric equivalent. The availability of age-matched normative data did provide meaningful scores to which the athlete's scores were compared, however control data proves invaluable in experiments evaluating meaningful change. McMillan et al. (2016) emphasised the beneficial nature of the inclusion of a control group that shared demographic characteristics.

The third limitation of the study related to the reporting of concussions within the sample over the course of the sporting season. As concussions were not explicitly recorded and available for analysis with the specifics of the injury, such as severity and the potential related neurocognitive deficits in the acute stage post-concussion, it was not possible to ascertain whether the potential deficits resolved or if they never occurred. The current study relied solely on self-report methods. As described by Covassin and Elbin (2010), self-reporting of concussions cannot be entirely entrusted and remains problematic and a burden for researchers and clinicians, as well as sports-management bodies. Furthermore, athletes remain reluctant to report concussions and the severity thereof due to fears of being temporarily or permanently withdrawn from play or demoted (Covassin and Elbin, 2010). Therefore, concussions sustained are often unreported and subsequently untreated. This particular limitation is shared with many retrospective studies in relation to absence of objective information regarding the amount and severity of sports-related concussions.

The fourth and final limitation of the study was lack of utilisation of alternate forms for some of the outcome measures. The current study did not use alternate forms for a number of the tests, however, given that 8-9 months had elapsed between Time 1 and Time 2, it is arguable whether the utilisation of alternate forms was completely crucial. However, the improvements in scores from pre- to post-season could potentially be explained by practice effects in the analysis of Hypothesis 1. On the other hand, the Reliable Change Index, utilised in order to examine Hypothesis 2, is conceptually designed to eliminate practice effects occurring in the analysis.

4.4 Clinical Implications

As no degradation of scores were found during analysis, there are few adverse clinical implications associated with the findings. At the group level analysis, no significant decreases were found across all outcome measures. At the individual level, two participants underwent significant degradation on one outcome measure. It was originally speculated that the finding of significant decline on test scores could prompt a potential query of the presence of PCS in athletes, as the deficits could be considered residual or persistent if found at post-season testing. The risk of returning to play prematurely and PCS or persistent neuropsychological sequelae in athletes has been highlighted by numerous studies as posing the danger of the development of progressive neurodegenerative diseases (McMillan et al, 2017; Smith, Johnson and Stewart, 2013).

4.5 Recommendations for Future Research

With regard to future research, there are several imperative aspects that can be taken away from the current study in order to ensure more robust, comprehensive testing of the relationship between sports-related concussion and neurocognitive deficits. Firstly, a larger sample size is recommended for future research in order to ensure sufficient power. Secondly, it is recommended that a control population is obtained and utilised in the study in order to ascertain whether changes found over time on neurocognitive tests within the contact group are a natural progression within the demographic, or due to participation in contact sport and the sustaining of concussions.

Further, it is recommended that more rigorous recording of concussions takes place during the sporting season. As previously mentioned, existing literature reports a discordance between concussions sustained in-play and self-reporting of concussions. Both self-report measures as well as stringent documentation of head injuries by management and clinicians should take place in accordance with one another, as previously recommended by Elbin and Covassin (2010). A multifaceted approach including the documentation of the amount of impacts sustained, severity and associated symptoms of each concussion is crucial in the assessment of degradation of neurocognitive function, as well being of utmost benefit in the making of return-to-play decisions.

The final recommendation to extract from the current study with regard to future research is the utilisation of alternate forms in testing all outcome variables, particularly when the RCI is not being utilised in analysis. Where alternate forms of neuropsychological outcome measures are not available, it is recommended that the RCI is used in analysis. The current study’s findings suggest that the lack of alternate forms may play a role in significant improvements seen across the sample at post-season testing.

4.6 Concluding Remarks

The findings of the current study are indicative that head impacts over one season of contact sport did not have a detrimental widespread effect on group scores on neurocognitive outcome measures. There were however, few significant individual degradations found on one outcome measure as previously discussed. The findings of this study are indeed of some reassurance in the context of the recent elevated concerns in relation to the adverse effects of head impacts in sport, and subsequently the potential development of progressive neurodegenerative diseases. The lack of statistically significant individual and group effects on neurocognitive scores over the sporting season may be of benefit in putting the risk of impact sports into perspective. However, it is of course worth noting that the lack of effects found in the current study is not generalizable to females, all age brackets, or to athletes enduring head impact over the course of lengthy periods of time – as the cohort of the current study is limited to school and collegiate age ranges and one season of contact sport. Furthermore, the potential effects of concussion and head impact on athletes over a longer time frame cannot be excluded and a prospective longitudinal study over a number of years is crucial in order to determine long-term consequences and the neurological sequelae of impact sports.

Although no significant degradation in scores were found at the group level, and few found at the individual level, the individual profile of athletes should be taken into account when determining the cognitive consequences of concussion. In particular, polymorphisms in genes such as APOE-e4, which has been found to play a role in the vulnerability of athletes to the sustaining of concussions (McAllister, 2010). The current study did aim to examine this variable but unfortunately due to the lack of availability of the relevant data, the progression of the analysis was impeded. Further studies taking into account the current recommendations are indeed required due to the potential risk to health and the development of progressive neurodegenerative diseases associated with repetitive head impact in contact sports previously reported in the literature.

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