

Recovery Process for Sports-Related Concussion Assessed with Precise Ocular Motility



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ABSTRACT

Ocular motility has been linked to Sports Concussion Assessment Tool 5 scores. However, the link between ocular motility changes and assessment result changes remains unclear. Hence, we investigated that potential link in patients with sports-related concussions. We retrospectively included participants aged ≥ 18 years who were diagnosed with a sports-related concussion. They underwent smooth pursuit eye movement assessment for allocation to the good improvement (rate of fundamental frequency $\geq 15\%$) or minor improvement ($< 15\%$) groups. Sports Concussion Assessment Tool 5 scores were determined at baseline and two weeks later, and score changes were compared between the groups. Thirteen men (mean \pm standard deviation age: 20.6 ± 5.0 years) were included: eight (19.0 ± 4.5 years) in the good improvement group and five (20.6 ± 5.7 years) in the minor improvement group. Symptom number (median = 2.0 vs. 0.0), symptom severity (median = 22.0 vs. 3.0), single-leg stance (median = 4.0 vs. 0.5), tandem stance (median = 1.0 vs. 0.0), and total errors (median = 5.0 vs. 0.5) were worse (all $p < 0.05$) in the minor improvement group. Smooth pursuit eye movement improvements measured using eye-tracking technology was linked to symptom recovery in patients with sports-related concussions. Therefore, ocular motility may be an objective indicator of sports-related concussions. Future studies with more patients are needed to confirm these findings.

Introduction

Sports-related concussions (SRCs) are among one of the most contentious topics in clinical practice owing to their non-specific symptoms and the lack of an established objective diagnostic method

[1]. Although computed tomography and magnetic resonance imaging are essential for diagnosing several types of brain injuries, objective diagnoses of SRCs cannot be achieved by imaging techniques, as this condition is often characterized by functional rather than structural anomalies [2]. Therefore, in daily clinical practice,

SRC is diagnosed based on various symptoms reported by athletes who suffer from head injuries.

The Sport Concussion Assessment Tool (SCAT) is the standard diagnostic method for diagnosing SRC. It was first introduced at the 2nd International Conference on Concussion in Sports in 2014 [3]. Since its introduction, the tool has undergone multiple revisions, and the 5th edition (SCAT5) is now the most widely used [4]. Evaluating SRC symptoms using the SCAT5 involves a symptom evaluation (by medical interview), cognitive screening (measuring orientation, immediate memory, and concentration and comprises digits and days of the week backward tasks), neurological screening (a balance test), and delayed recall. However, the SCAT5 scores should not be used as the sole basis for diagnosing concussions, as an indicator of post-SRC recovery, or to determine whether an athlete can return to play. Moreover, since the SCAT5 includes assessments based on subjective symptoms, score improvements may result from inaccurate answers [5–7]. Further, although SCAT5 is the recommended standard tool for assessing SRC, its subjective indicators are inconsistent with the neurophysiological recovery process [8–10]. In other words, a SCAT5 assessment should be complemented with an objective evaluation of the SRC symptoms.

While the cornerstone of SRC treatment is adequate physical and cognitive rest, the risk of underreporting symptoms in athletes who want to accelerate their recovery may lead to premature return to play. Therefore, the SRC recovery process should be further evaluated using objective indicators.

Ocular motility disorders, one objective SRC symptom, has been reported in 40–90% of patients with an SRC [11–13]. Furthermore, ocular motility has been associated with SRC symptoms, making it a potential SRC screening tool [14]. However, ocular motility measurements are not included in the SCAT5, and no studies have investigated the association between ocular motility and symptom recovery in patients with an SRC. If a relationship exists between SRC symptoms and the objective assessment of ocular motility disorders in these patients, then ocular motility evaluations could be valuable for assessing the recovery process for SRC. Furthermore,

precise ocular motility evaluation using an eye tracking system is important.

Therefore, the present study aimed to investigate the potential link between ocular motility improvements and symptom recovery using the SCAT5 in patients with SRC.

Materials and Methods

Ethical considerations

The study procedures adhered to the tenets of the Declaration of Helsinki (1964) and its later amendments. The study was approved by our institute's ethics committee (protocol No. 3628, approved on August 28, 2017). The study was approved by the appropriate Ethics Review Board. The study procedure and objectives were explained to the participants who provided informed consent before the study's commencement.

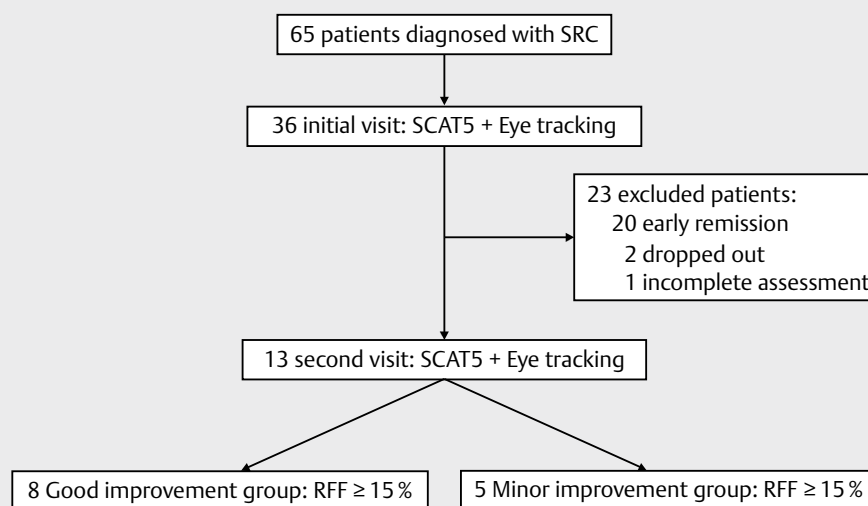
Study design and participants

This study involved a retrospective analysis of a case series. Sixty-five participants ≥ 18 years old with an SRC diagnosis at our institution's Sports Concussion Clinic were recruited between April 2018 and March 2022. Of the 65 participants, 36 consented after hearing the study's purpose and details. Finally, 13 participants were included in the analysis after excluding 20 patients in early remission, two dropouts, and one patient who did not complete the assessment (► Fig. 1).

Data collection

Basic information

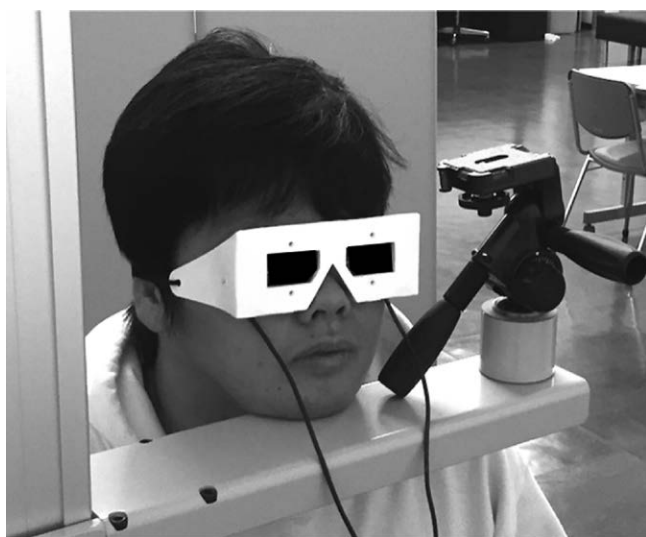
The following basic attributes were collected: age, sex, sport, role/position, and the number of days elapsed since injury. SRC symptoms were evaluated using the SCAT5 scores and ocular motility disorder assessment at the initial visit and two weeks later.



► Fig. 1 Flowchart of participant recruitment process and group allocation. SCAT5, Sports Concussion Assessment Tool 5; SRC, sports-related concussion.

Eye tracking

To assess ocular motility disorders [15], smooth pursuit eye movement (SPM), a type of eye movement in which the eyes remain fixated on a moving object, was measured using an optical device (infrared scleral reflection method). The distance from the target object was fixed at 1 m. In the SPM assessment, the participants were asked to gaze at a visual target rotating at a constant velocity of 3 s/cycle (30°/s), and their eye-movement waveforms in the horizontal and vertical directions were measured. Fourier transform was then applied to the measured waveforms to extract the frequency components. After calculating the rate of fundamental frequency (Rff), an Rff of $\geq 15\%$ was classified as normal (► Fig. 2).



► **Fig. 2** Ocular motility assessment setup. Patients wore infrared goggles and maintained a fixed head position, and their eye movements following the LED light source were measured. LED, light-emitting diode.

► **Table 1** Study participant characteristics.

No.	Age	Sex	Sport	Position	Days elapsed since SRC	1 st SPM	2 nd SPM
1	21	M	Football	FW	5	16	
2	19	M	Football	FW	3	17	
3	18	M	Rugby	BK	4	17	
4	32	M	Baseball	–	7	17	
5	19	M	American Football	TE	6	13	
6	17	M	Judo	–	2	14	
7	18	M	Football	FW	3	12	
8	19	M	Football	DF	4	14	
9	17	M	Rugby	BK	3	12	
10	32	M	Football	MF	4	14	
11	21	M	American Football	RB	3	13	
12	17	M	Judo	–	2	15	
13	18	M	Football	FW	3	17	

BK, back; DF, defender; FW, forward; MF, midfielder; TE, tight end; RB, running back; SPM, smooth pursuit eye movement; SRC, sport-related concussion.

SCAT5

The SCAT5 comprises six steps, but Step 1 (athlete background) and Step 6 (decision) were excluded from the analysis because only Steps 2–5 allowed scoring for SRC symptoms. Scores were calculated for each of the sub-items: Steps 2, 3, 4 and 5.

Group allocation and comparisons

The SCAT5 scores of the participants at the initial visit and two weeks later were compared to check for improvements. Patients with an Rff of $\geq 15\%$ after two weeks were assigned to the good improvement group, whereas those with an Rff of $< 15\%$ were assigned to the minor improvement group. The scores for each SCAT5 sub-item obtained two weeks later were compared between the groups to examine differences in residual SRC symptoms.

Statistical analyses

The statistical program JMP Pro 15.1.0 (SAS Institute, Cary, NC, USA) was used for the statistical analysis. A Wilcoxon signed-rank test was used for comparisons with a significance level of less than 5%.

Results

Basic characteristics

The median age of the 13 participants was 19.0 years (quartile 18.0–21.0 years), and all participants were men. Moreover, six participants practiced football, two practiced American football, two practiced rugby, one practiced baseball, and one practiced judo. The median number of days elapsed since the injury was 3.8 (quartile 3.0–4.0 days) (► Table 1).

Eye tracking and ocular motility changes

Based on the SPM assessment, eight patients were assigned to the good improvement group, and five were assigned to the minor improvement group.

SCAT5 score changes two weeks after the initial assessment

Compared to the minor improvement group, the good improvement group showed significant improvements in symptom number and symptom severity, immediate memory, double-leg stance, single-leg stance, tandem stance, and total errors, and delayed recall after two weeks compared with that at the initial evaluation (► Table 2).

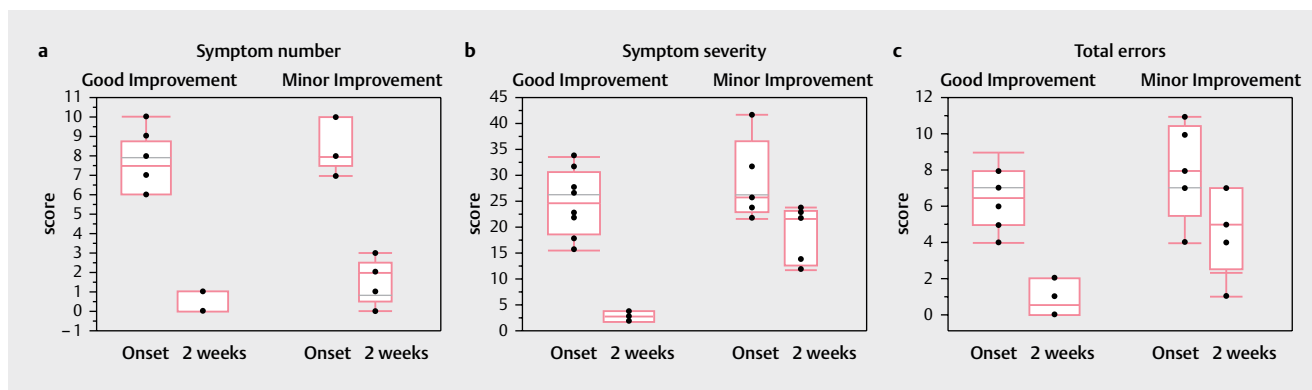
SCAT5 score comparisons between the good and minor improvement groups

Initially, all 13 patients had ocular impairment and an Rff $< 15\%$; after two weeks of initial evaluation, eight patients reached an Rff of $\geq 15\%$ (i. e., the good improvement group). Thus, the SCAT5 scores after two weeks were compared between the good and minor improvement groups. Scores for symptom number (median = 2.0 vs. 0.0; $p = 0.042$) and symptom severity (median = 22.0 vs. 3.0; $p = 0.003$) as well as for single-leg stance (median = 4.0 vs. 0.5; $p = 0.006$), tandem stance (median = 1.0 vs. 0.0; $p = 0.035$), and

► **Table 2** SCAT5 steps for all participants (N = 13).

SCAT5 STEP	Evaluation items	Scale	Onset		Two weeks after		Calc. p-value
			Mean (SD)	Median	Mean (SD)	Median	
2	Symptom number	0–22	7.9 (1.44)	8	0.85 (0.94)	1	<0.001
	Symptom severity	0–132	26.7 (6.80)	26	9.15 (8.40)	4	<0.001
3	Orientation	0–5	4.69 (0.46)	5	4.92 (0.27)	5	0.250
	Immediate memory	0–30	21.6 (3.79)	21	24.7 (2.61)	24	<0.001
	Concentration	0–5	4.31 (0.72)	4	4.69 (0.46)	5	0.188
4	Double-leg	0–10	1.23 (0.70)	1	0.23 (0.42)	0	0.001
	Single-leg	0–10	4.38 (0.84)	4	1.54 (1.55)	1	<0.001
	Tandem stance	0–10	1.46 (1.15)	1	0.62 (0.74)	0	0.016
	Total errors	0–30	7.08 (2.68)	6	2.38 (2.71)	1	<0.001
5	Delayed recall	0–10	6.38 (1.33)	6	8.00 (0.78)	8	0.001

SCAT5, Sports Concussion Assessment Tool 5; SD, standard deviation.

► **Fig. 3** Differences in SCAT5 score; **a.** Symptom number (Step 2); **b.** Symptom severity (Step 2); and **c.** Total errors (Step 4) at the initial visit and two weeks later.► **Table 3** SCAT5 score improvements in participants with minor and good ocular motility recovery.

SCAT5 STEP	Description	Scale	Minor improvement (N = 5)		Good improvement (N = 8)		Calc. p-value
			Median	Quantile	Median	Quantile	
2	Symptom number	0–22	2.0	0.5–2.5	0.0	0.0–1.0	0.042
	Symptom severity	0–132	22.0	13.0–23.5	3.0	2.0–4.0	0.003
3	Orientation	0–5	5.0	5.0–5.0	5.0	5.0–5.0	0.429
	Immediate memory	0–30	23.0	22.0–24.0	25.0	23.3–28.8	0.086
	Concentration	0–5	5.0	4.0–5.0	5.0	4.3–5.0	0.584
4	Double-leg	0–10	0.0	0.0–1.0	0.0	0.0–0.0	0.271
	Single-leg	0–10	4.0	2.0–4.0	0.5	0.0–1.0	0.006
	Tandem stance	0–10	1.0	0.5–2.0	0.0	0.0–0.8	0.035
	Total errors	0–30	5.0	2.5–7.0	0.5	0.0–2.0	0.014
5	Delayed recall	0–10	8.0	7.0–8.5	8.0	7.3–9.0	0.485

SCAT5, Sports Concussion Assessment Tool 5.

total errors (median = 5.0 vs. 0.5, $p = 0.014$), were significantly worse in the minor improvement group than in the good improvement group (► **Fig. 3**). However, orientation, immediate memory, and concentration as well as double-leg stance and delayed recall did not differ between the two groups (► **Table 3**).

Discussion

In this study we investigated the potential link between the extent of ocular motility improvement and symptom reduction in patients with SRC and found that the group of participants with a higher degree of ocular motility improvement also had better recovery from SRC symptoms.

SCAT5 scores improve over time during the recovery phase [8–10], and our results are consistent with this finding; the scores for most SCAT5 sub-items improved significantly over the two-week recovery period. Notably, differences between the minor and good improvement groups were observed only for subjective symptoms, such as symptom number and symptom severity (Step 2), and balance functions, such as tandem stance and total errors (Step 4). A previous study associated ocular motility disorders with subjective symptoms in patients with mild traumatic brain injury [16], demonstrating that patients with SRC and residual ocular motility disorder symptoms also reported residual subjective symptoms of SRC; our findings align with the findings of this previous study.

Visual information plays a major role in postural control relative to the vestibular system [17–20]. Therefore, it is likely that patients with residual ocular motility deficits would also have residual balance disorder symptoms. In contrast, orientation, immediate memory, and concentration (Step 3), as well as double-leg stance (Step 4) and delayed recall (Step 5), did not differ between the two groups. As Step 3 and its five sub-items were used to evaluate cognitive function, it was not considered to be associated with ocular motility. Moreover, the lack of difference in double-leg stance (Step 4), an extremely easy task in which both groups scored 0, was thought to be due to the floor effect.

This study has some limitations, including its small sample size and selection bias regarding sports and sex. To ensure the generalizability of our findings, a study with more patients should be performed. Furthermore, the ocular motility assessment used in this study required specialized equipment, measurements, and specific analytical techniques. Therefore, future studies should consider simpler measurement methods for clinical practice.

In conclusion, precise ocular motility assessments using eye tracking technology could be useful for objectively assessing SRC symptoms during recovery, especially if used with an evaluation tool, such as the SCAT5, for a definitive diagnosis.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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