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A Systematic Review of Criteria Used to Define Recovery from Sport-Related Concussion in Youth Athletes

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Abstract

Objective—The Concussion in Sport Group guidelines recommend a multifaceted approach to help clinicians make return to sport decisions. The purpose of this study was to identify the most common multifaceted measures used to define clinical recovery from sport-related concussion in young athletes (high school and/or college level) and to summarise existing knowledge of criteria used to make return to sport decisions.

Design—Systematic review

Data Sources—The PubMed (MEDLINE), SPORTDiscus, and Embase electronic databases were searched from January 1, 2000 to March 1, 2017 by 3 independent reviewers.

Eligibility criteria—Inclusion criteria: elementary, high school and college age groups, and a specific definition of clinical recovery that required two or more measures. Exclusion criteria: review articles, articles using the same sample population, case studies, non-English language, and those that used one measure only or did not specify the recovery measures used.

Study quality—Study quality was assessed using the Downs and Black Criteria.

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Declarations

Ethical Approval: Not applicable.

Competing interests: The authors declare no conflict of interest.

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Results—Of 2,023 publications, 43 met inclusion criteria. Included articles reported the following measures of recovery: somatic symptom resolution or return to baseline (100%), cognitive recovery or return to baseline (86%), no exacerbation of symptoms on physical exertion (49%), normalisation of balance (30%), normal special physical examination (12%), successful return to school (5%), no exacerbation of symptoms with cognitive exertion (2%), and normalisation of cerebral blood flow (2%). Follow-up to validate the return to sport decision was reported in 8 (19%) articles. Most studies were case-control or cohort (Level of Evidence 4) and had significant risk of bias.

Conclusion—All studies of sport-related concussion use symptom reports to define recovery. A minority of studies used multiple measures of outcome or had clearly defined recovery criteria, the most common being a combination of a self-reported symptom checklist and a computerized neurocognitive test. Future studies ideally should define recovery a-priori using objective physiological measures in addition to symptom reports.

Prospero Systematic Review Registration—CRD42016032373

Key Terms

Sport-related concussion; recovery; mild traumatic brain injury; student athlete; return to play

Introduction

Concussion incidence is significant in contact sport and recreational activities.[1] In 2006 1.8 to 3.8 million sport-related traumatic brain injuries were estimated to occur annually in the US. The majority of these are sport-related concussions.[2] Although there is some ambiguity in the definitions of mild traumatic brain injury and concussion, the term concussion is generally used in sport-related injuries.[3] Concussion occurs when sudden deceleration and rotational forces applied to the brain [4] trigger an acute and subacute pathophysiological metabolic response in the absence of gross brain lesions.[5] Concussion results in somatic, cognitive and emotional symptoms, cognitive impairment, abnormal physical examination findings, behavioral issues, and sleep disturbance.[6] Many patients with sport-related concussion recover within 7 – 10 days [78] although a recent study in adolescents, which defined recovery as normalisation of physiological, visual and balance function,[9] reported that recovery typically required 3–4 weeks.

The most widely accepted guidelines for return to sport are the Concussion in Sport Group (CISG) guidelines. The most recent are from the Berlin 5th International Conference on Concussion in Sport that recommend a multifaceted evaluation to include physical examination, neuropsychological testing, and a graded return to activity to help determine recovery from concussion. The latest CISG guidelines state that athletes should return to a baseline level of symptoms but do not provide definitions to establish when an athlete is fully recovered physiologically and ready to return to sport. Resolution of symptoms is recognised as a critical part of recovery but symptom reporting alone is problematic because athletes often under-report symptoms,[10] some concussion-related symptoms are reported in populations without concussion,[11] and symptoms are not specific to concussion.[12]

While the CISG guidelines recommend that symptom and cognitive recovery must occur before athletes can return to sport, actual clinical practice may differ.[13] Buckley et al.[14] found that 65% of athletic trainers used a multifaceted assessment to establish recovery from sport-related concussion while 11% used only one or no assessment tool when deciding on return to sport. The most frequently used assessments were symptom reports (92%), clinical examination (86%), computerized neuropsychological testing (74%), balance testing (65%), and the Standard Assessment of Concussion (SAC) (54%).

An evidence-based definition of recovery from concussion is important given the risk of more severe consequences should repeat injury occur before resolution of the first concussion[15] and increased awareness of possible long-term effects of concussion.[16] The test-retest reliability and internal consistency of Immediate Post-concussion Assessment and Cognitive Testing (ImPACT),[17] the Buffalo Concussion Treadmill Test (BCTT),[18] and the Sport Concussion Assessment Tool (SCAT)[19] have been reported on but not for other measures. The international consensus meetings on concussion in sport[67] has stated that a single criterion may not be sufficient to define concussion recovery; hence, we included only research articles that used at least two measures to define recovery from sport-related concussion. We chose the age groups of elementary, high school and college athletes for this systematic review because of the abundance of research specific to them. There are not many publications on athletes older than college age or in athletes under the age of twelve. [20] The purpose of this systematic review was to summarise the criteria that have been used to define recovery after sport-related concussion. Study quality was assessed to identify areas of potential improvement for future studies.

Methods

This review was prospectively registered on 18 January 2016 in the PROSPERO database (registration number: CRD42016032373)[21].

Selection criteria

We included articles published in English that described sport-related concussion and included elementary school, high school and college age athletes. Articles had to report the recovery criteria and use at least two measures. We included those articles that were published since 2000 because of the change of definition of concussion and recommendations for sport concussion management in 2001.[22] Cohen's Kappa was used to measure inter-rater reliability between reviewers for article selection.

Exclusion criteria: review articles, case reports, and articles that did not clearly define recovery measure(s) used. For articles reporting on the same sample population, we included the study that reported recovery measures. If all reported recovery measures, then only the earliest article was included. We excluded articles that measured the time it took for specific clinical symptoms to resolve or for cognition to return to baseline but did not state that the athlete had recovered or was ready to return to sport or to school since normalisation of symptoms is not the same as clinical recovery. We also excluded articles where a physician had documented recovery independent of the study but did not specify the basis for this clinical decision. We excluded articles that stated the CISG Guidelines were used but did not include sufficient detail about implementation of the return to sport protocol. Some patient samples were not exclusively sport-related concussion. Here, we identified the mechanism of injury and included the article only if the mechanism of injury for a majority (>50%) of subjects was sport-related concussion or similar to it and the participants received treatment similar to that used for sport-related concussion.

Literature search

We searched the PubMed (MEDLINE), SportDiscus and Embase electronic databases in March 2017. Search terms included: "Concussion AND recovery AND (athlete OR sport) AND (children OR youth OR teens OR teenagers OR college OR high school); Concussion AND symptoms AND (athlete OR sport) AND (children OR youth OR teens OR teenagers OR college OR high school); and Concussion AND resolution AND (athlete OR sport) AND (children OR youth OR teens OR teenagers OR college OR high school)". Exact search syntax is provided. PRISMA[23] flow chart was made.

Three reviewers independently screened the titles and abstracts of all articles identified in the electronic database search. If it was unclear from the title and/or abstract whether the article should be included, the full text of the article was obtained and independently screened by the 3 reviewers. Any discrepancies were resolved by consensus.

Data extraction

The following variables were independently extracted from each article by 3 reviewers: first author, year, study design, sample size, patient age, time to recovery, and the definition of recovery. Methods of assessing and conclusions pertaining to post-recovery follow-up were also extracted when reported.

Recovery measures were categorised as:

1. symptoms
2. cognitive performance at rest (computerised or paper-pen neurocognitive tests)
3. special physical examination
4. balance
5. symptom exacerbation during physical exertion
6. symptom exacerbation during cognitive exertion
7. ability to maintain academic performance
8. special tests (e.g. cerebral blood flow)

Risk of bias and level of evidence

We assessed risk of bias of included articles using the Downs and Black checklist for methodological quality[24]. Level of evidence was determined according to the guidelines by Melnyk et al.[25] This system uses a seven level grading system that begins with systematic review of randomised controlled trials (Level 1) down to expert opinion (Level 7).

Results

Literature search

The literature search yielded a total of 2,294 articles (Figure 1). The titles and abstracts of 2,023 non-duplicate articles were screened and the full texts of 261 articles were evaluated. Two hundred and seven articles were excluded for not meeting recovery definition criteria and 11 articles were excluded during data extraction because their recovery criteria were not specific or were incomplete. Forty-three articles were included in this systematic review (Table 1). Cohen's Kappa of inter-rater reliability for article selection was 0.61. Three articles had a minority (<50%) of subjects with concussion from non-sport activities. They were included because the authors specifically stated that the mechanism of injury and treatment of the non-sport-related concussion were similar to that of sport-related concussion.

Excluded articles

Out of 207 excluded articles, 28 used only one recovery measure (either symptoms or neurocognitive testing), 37 monitored symptom recovery but participants were not defined as clinically recovered in the study, 1 was a study of sport-related concussion in adults, and 141 either did not specify any recovery criteria or did not monitor recovery. The eleven articles excluded during data extraction were: Hang et al.[26] and Kelty-Stephen et al.[27], which used neurocognitive testing and symptoms to measure recovery but stated that recovery was defined as resolution of symptoms and that the neurocognitive tests were just being validated. Kontos et al.[28] used neurocognitive tests, a mood test, or professional recommendation to describe recovery but did not mention the basis for the professional recommendation or how many of the participants were cleared exclusively due to the professional recommendation. Moser et al.[29] used ImPACT, which includes neurocognitive measures and a symptom checklist, and mentioned that a portion of subjects had fully recovered by the time of their last visit but did not state whether ImPACT was the main tool to determine return to sport or if it was the physician's decision. Madura et al.[30] measured concussion severity rather than recovery. The Meier et al.[31] study was excluded because it did not specify which aspect of the CISG Guidelines was used to determine recovery. Studies that used the same sample were excluded. Lau et al.[32], Lau et al.[33] and Lau et al.[34] Darling et al.[35] and Baker et al.[36], and Henry et al.[37] and Henry et al.[38] used the same sample so only the earlier studies were included. Kostyun et al.[39] examined several parameters (symptoms, cognitive impairment, return to learn, and a special physical examination) but defined recovery only by symptoms returning to baseline.

Risk of bias assessment and level of evidence

Thirty eight out of 43 studies were case-control or cohort studies (level of Evidence 4).[25] Study quality according to the Downs and Black Criteria[24] is presented in Table 2. Some of the Downs and Black questions did not apply to most of the studies since they were not randomized trials. Except for Maerlender[40], only questions 1–3, 5–7, 10–12, 16–18, 20–22 and 25 were relevant to the majority of the studies. Most studies were of low quality (case-control or cohort, Level of Evidence 4) and had significant risk of bias (Downs and Black score < 14). Studies in general had well defined objectives (Q1), main outcomes (Q2), and patient characteristics (Q3). Principal confounders (Q5) were not documented in some of the studies. The main findings (Q6), the random variability (Q7), probability values (Q10) and source population (Q11) were clearly documented in almost all studies. Most studies did not mention the proportion of the potential participants who agreed to participate in the study (participant representation, Q12). Most studies had appropriate internal validity (Q16–18 and Q20–22) except that there was very little adjustment for confounding variables (Q25).

Recovery measures

All 43 studies reported symptom recovery, thirty-seven studies (86%) used neurocognitive testing, twenty-one (49%) used a provocative exercise test, thirteen (30%) used normalisation of balance, five (12%) used a special physical examination, two (5%) used successful return to school, one (2%) used absence of symptoms during cognitive exertion, and one (2%) used normalisation of cerebral blood flow.

All of the included studies used symptom recovery according to the following checklists: 31 used either the Post-Concussion Symptom Scale (PCSS, which is part of the Sport Concussion Assessment Tool [SCAT]), or the symptom checklist from ImPACT, 1 used CogSport for Kids, 2 used the Graded Symptom Checklist (GSC), 1 used the Post-Concussion Symptom Scale-Revised (PCS-R), 1 used CNS Vital Signs, 2 used the Post-Concussion Symptom Inventory (PCSI), 1 used the Subjective Symptom Rating scale, 1 used the Rivermead Post-concussion Symptom Questionnaire, and 3 listed patient-reported symptoms or did not specify the symptom instrument used. Seven studies[323641–45] used a cut off of a minimal symptom score (less than 7 out of a maximum of 132), 14 studies[3746–58] used the cut off of “symptom-free” (symptom score = 0), and 10 studies[4059–67] used “return to baseline symptoms” as their recovery measure. The other studies did not specify what qualified as a normal level of symptoms or did not use a 22-symptom Likert-scale checklist.

The most common computerised cognitive test was ImPACT (27 studies), 1 used CogSport, 1 used Axon Computerized Cognitive Assessment Tool, 1 used CNS Vital Signs, 5 used a paper-pencil test, and two did not specify. One study[35] initially used the Automated Neurophysiological Assessment Metrics (ANAM) but changed to ImPACT. Seventeen studies used a non-specific definition of provocative exercise to test for exacerbation of symptoms, i.e., ‘no exacerbation of symptoms on exertion’. Four studies systematically assessed exercise tolerance: 3 used the Buffalo Concussion Treadmill Test (BCTT) and 1 clearly described the return to sport protocol from the 2012 CISG guidelines. For balance measures, 11 used the Balance Error Scoring System (BESS, which is also part of the SCAT), 1 used the Sensory Organization Test (SOT), and 1 did not specify how balance was assessed.

Combined recovery criteria

Table 4 is the contingency table for the recovery criteria (see data extraction) employed in each study. Eleven out of 43 studies used a combination of somatic symptom scales and cognitive performance to assess recovery representing the most common multi-modal recovery battery employed. The remaining 32 studies used some combination of the 8 recovery measures.

Post-recovery follow-up

Eight articles out of 43 (19%) followed up with subjects after recovery. The details of post-recovery follow-up and results are in Table 5. We note that it is not standard clinical practice to perform post-recovery surveillance because return to sport without symptoms is considered to be a successful outcome.

Discussion

We systematically reviewed the literature for the most common measures used to make the return to sport decision after sport-related concussion. Given that the definition of concussion varies across the literature, it was not surprising that investigators varied in what criteria they used for return to sport. There are many studies that describe recovery from concussion but most do not indicate what measures were used to objectively make the return to sport decision. This is important for possible replication. It has been suggested that multiple measures should be used to make the return to sport decision from concussion but our search revealed that most studies used only one outcome measure (usually symptom resolution). The studies that used more than one recovery measure, those that qualified for inclusion in this review, used different combinations of measures.

Level of Evidence and Study Quality

Most of the studies were cohort or case-control studies. For study quality, the major source of bias was lack of documentation of principal confounders. History of previous concussions, for example, may be associated with longer duration of recovery and should always be documented.[6869] This could be due to the studies not documenting confounding variables or that appropriately matched controls were not employed.

Symptom resolution

Symptom resolution was the most common measure used to make the return to sport decision-all included studies used some version of a symptom assessment. The challenge for clinicians is that symptom reports are non-specific and may not coincide with brain recovery since physiological abnormalities (e.g., CBF, DTI) persisting beyond reported symptom resolution have been reported in multiple studies of sport-related concussion.[70] Symptom recovery was not, however, defined always as an “asymptomatic state”. Healthy adolescents have been reported to have symptom severity scores of up to 6 (out of a maximum of 132) when given concussion symptom checklists;[71] hence, several studies used a cut off score of less than 7 to define symptom recovery. Some studies used “return to baseline” and some used the terms “asymptomatic” or “symptom score of 0” to define symptom recovery. We found only two articles[7273] that did not use symptoms as a recovery criterion but since they used only one measure to define recovery (i.e., neurocognitive testing), they were not included in the final sample. Symptoms are usually assessed by symptom checklists. Concussion symptoms, however, are not specific to concussion. Leddy et al.[12], for example, found no difference in the symptom patterns reported by those with concussion when compared with those who had cervical and vestibular issues.

Neurocognitive testing

The second most common measure used for the return to play decision was return to baseline using neurocognitive testing, usually with a computer test like ImPACT. ImPACT assesses symptoms and aspects of cognition including visual memory, verbal memory, visual motor speed, and reaction time that can be compared with individual pre-injury or age-normative values. The other computerised neurocognitive tests used were ANAM[74], Axon Computerized Cognitive Assessment Tool, CogSport for Kids[75] and CNS Vital Signs[76], which are similar to ImPACT in that they measure different aspects of cognition and have a symptom checklist. Computerised neurocognitive tests can be administered in a 25 to 30-minute sitting and are used widely throughout the world. However, there are limitations of these tests with respect to re-test reliability. For example, the intraclass correlation coefficient for ImPACT has been reported to range between 0.15 to 0.39.[77] Pen and paper tests (Children's Color Trails, Rey Auditory Verbal Learning Test, Rey Complex Figure Test, Stroop Color and Word Test Children's version, Symbol Digit Modalities Test, Trail Making Test-B, and Digit Symbol Substitution Test) have the limitation that they need a neuropsychologist to interpret the results and are not reliable when used in succession due to the learning effect.[42]

Physical exertion testing

The CISG Guidelines' Graduated return to sport strategy is a clinical guideline that can be adapted to specific sports. Exacerbation of symptoms at any level is a reason to return to the previous step until the athlete can exercise without symptoms at the level of exertion required for that sport. The principle of return of normal exercise tolerance has been used in 21 studies to establish physiological recovery from concussion. Three of the studies systematically evaluated exercise tolerance after concussion using the Buffalo Concussion Treadmill Test (BCTT), all from the institution where the test was developed. This test is considered to be a clinical measure of autoregulation of cerebral blood flow (CBF) during exercise.[41] It has been used to establish physiological recovery from concussion in adolescents after sport-related concussion.[35] The BCTT is the only functional test that has been shown to safely[78] and reliably[18] diagnose and establish recovery from exercise intolerance[35] after sport-related concussion and is used throughout the world in the assessment of athletes after head injury.

Balance and special physical examination tests

We included those measures that are considered to be more concussion-specific, e.g., the vestibular-ocular examination.[79] Balance is an important criterion for the return to sport decision since persisting and untreated balance deficits could lead to future injuries on the playing field.[32] The most common balance measure used was the BESS test, which is part of the SCAT. Vestibular components of the physician physical examination that measure balance, such as tandem gait, might have been used but the studies that utilised a physical examination did not provide a description of the elements performed. There is a clear need for a sensitive and a specific physical examination that includes the elements most related to the injury that produces concussion; specifically, the cervical, oculomotor and vestibular systems. A concussion-relevant physical examination could help clinicians not only with diagnosis but also to establish recovery from concussion.[80]

Physiological measures

fMRI with N-Back testing[59], resting CBF [81], and EEG [82] have been used to try to establish concussion recovery using physiological parameters that do not involve motivation or effort. There is discordance between normalisation of these tests and symptom resolution. Physiological assessment of concussion has the potential to establish objective "physiological biomarkers" of recovery. Physiological tests, however, require validation in larger and more diverse samples because some participants had abnormal fMRI, CBF and brain electrophysiological measures despite reporting symptom resolution. The clinical significance of these measures and whether they represent ongoing neuronal or cerebrovascular damage, recovery or adaptation remains unknown.

Studies assessing return to sport follow-up and their implications for concussion assessment

Validation of the return to sport decision made by clinicians can be established if athletes who were returned to sport after concussion did not have return of symptoms while playing their sport. Eight articles in this systematic review evaluated the return to sport decision and they were diverse in terms of the length of time to follow up. Among high school athletes, 39% who returned to sport (after apparent recovery based on symptom resolution and normalisation of cognitive performance, balance, and exercise tolerance on the BCTT) reported new or increased problems upon return to school[35] (although it was not clear whether return to school occurred within or beyond the typical timeframe for recovery). Over a quarter (28%) of athletes diagnosed as being recovered from concussion demonstrated cognitive impairment on ImPACT after moderate physical exertion[45],suggesting that physical exertion precipitated cognitive problems not identified at rest. On the other hand, physical exertion appears to adversely affect ImPACT scores[83], suggesting that it might not be appropriate to administer the test immediately after training or games. Multimodal testing on a weekly basis for up to 1 month following sport-related concussion (including general health questionnaires, symptoms, neurocognitive and balance testing, and exertion testing) may the best approach for determining recovery from concussion in young athletes. [84,42,60,66] However, more research on multimodal measures of recovery after concussion is needed.

Limitations

A limitation of this study is the inability to also perform a meta-analysis with the data. Table 4 shows the heterogeneity in the return to sport criteria used across studies thus preventing a meta-analysis of the 43 studies. Furthermore, while some of the studies employed similar return to sport criteria (e.g., Row 1 of Table 4), they did not provide individual patient level data but merely summary statistics with little uniformity in the provided summary statistics. These reasons make a meaningful meta-analysis impossible. Average return to sport times reported for the same set of criteria used by different studies are not truly comparable given the different study inclusion criteria and variable or undefined treatment.

Our systematic review is at risk of publication bias since we only included published, peer-reviewed articles and we could not search all the grey literature. There is also a risk for language bias since we only included English language articles. In addition, some researchers may have used additional measures for the return to sport decision that were not mentioned in their studies. Recent research has identified the frequency and importance of oculomotor dysfunction as an objective indicator of concussion.[85] The King Devick Test for visual tracking has been shown to be sensitive for diagnosing concussion[86–88]. Oculomotor testing, however, has been used primarily to diagnose concussion and not as much to establish concussion recovery. Return to baseline on neurocognitive testing can be determined using a Reliable Change Index (RCI). ImPACT uses RCI but studies using other neurocognitive tests did not report using an RCI.

Three articles included concussions that were not exclusively sport-related. Corwin et al.[89] and Crowe et al. [42] had 23% and 40% non-sport-related concussion subjects, respectively. They clearly mentioned that the mechanisms of injury were similar to sport-related concussion and that the concussions were treated like sport-related concussion. Brown et al. [90] included a "majority of sport-related concussion" and said that their sample was treated like sport-related concussion.

Future research

A more objective definition of sport-related concussion is needed so that we may better establish valid return to sport criteria. Future studies must define their return to sport criteria a-priori, use validated measures whenever possible, and until a universally accepted definition of concussion is reached, use a multi-modal approach to decide readiness to return to sport. This could encompass return to a baseline or normal level of symptoms, return to baseline or to normal cognitive performance, a normal physical examination (based on physical examination elements pertinent to concussion) and, in certain cases, demonstrating normal exercise tolerance on a graded physical exertion test.

Conclusion

There has been much written and studied about recovery from concussion, especially in the last ten to fifteen years. Only a minority of studies used multiple measures of recovery and had clearly defined return to sport criteria. The most common combination was self-reported symptom checklists and computerized neurocognitive tests. Second was the combination of self-reported symptoms, a computerized neurocognitive test, and a physical exertion test. We conclude that there are disparate measures of recovery being used in sport-related concussion research, that the research is of limited quality and subject to bias, and that it has led to conclusions with limited applicability. We recommend that a consensus be reached in the discipline regarding a set of reliable measures to make the return to sport decision. This would promote consistent study design in sport-related concussion research as well as uniform and safe applications of return to sport strategies.

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Summary Box

What are the new findings?

- Since the year 2000, 43 papers that defined recovery from sport-related concussion using two or more measures were identified.
- All of the included articles used symptom recovery, 86% used cognitive recovery, 49% used response to physical exertion, 30% used balance testing, 12% used a special physical examination, 5% used return to full academic activities, 2% used a cognitive exertion test, and 2% used normalisation of cerebral blood flow.

How might it impact on clinical practice in the near future?

- Researchers and physicians are encouraged to use standardized multiple criteria to establish recovery from sport-related concussion. Examples of these include normalisation of symptoms, a concussion-relevant physical examination, cognitive performance, and exercise tolerance.

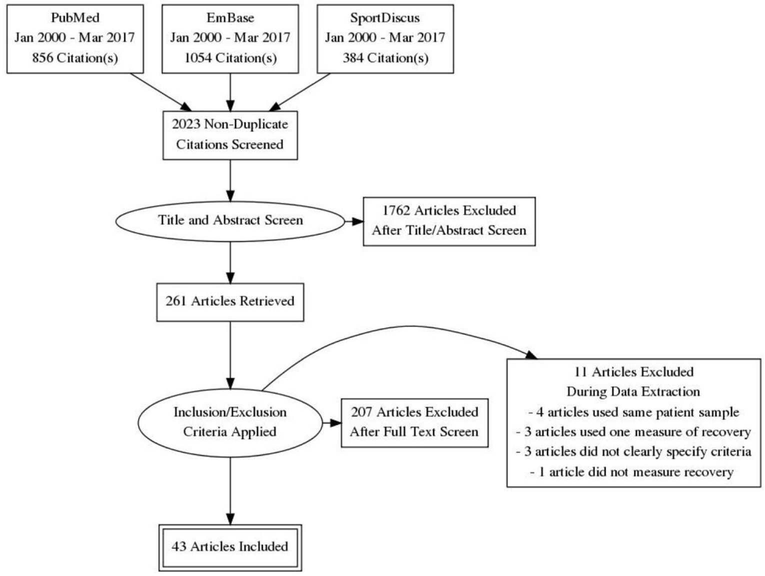
PubMed
Jan 2000 - Mar 2017
856 Citation(s)
EmBase
Jan 2000 - Mar 2017
1054 Citation(s)
SportDiscus
Jan 2000 - Mar 2017
384 Citation(s)
2023 Non-Duplicate
Citations Screened
Title and Abstract Screen
1762 Articles Excluded
After Title/Abstract Screen
261 Articles Retrieved
11 Articles Excluded
During Data Extraction
- 4 articles used same patient sample
- 3 articles used one measure of recovery
- 3 articles did not clearly specify criteria
- 1 article did not measure recovery
Inclusion/Exclusion
Criteria Applied
207 Articles Excluded
After Full Text Screen
43 Articles Included

Figure 1.

Table 1

Study Characteristics

First Author	Year	Study Design	Sample Size (Control Sample Size)	Age in years (Controls age in years)	Time to return to sport in days (Controls return to sport time)
Anzalone [91]	2017	Prospective cohort study	167	15 ± 2	19.9 ± 13.4
Baker [92]	2016	Retrospective cohort study	147	15.4 ± 1.5	16.5
Black [64]	2017	Retrospective chart review	759	19.34 ± 1.81	Median = 11
Broglio [93]	2016	Prospective cohort study	24 (21)	16.7 ± 2.5 (17.1 ± 2.9)	26.2 ± 42.8
Brooks [51]	2016	Retrospective cohort study	75 (182)	19.3 ± 1.3 (19.9 ± 1.3)	21.0
Brown [90]	2014	Prospective cohort study	335	15 ± 2.6	43 ± 53
Buckley [47]	2015	Prospective cohort study	25 (25)	19.8 ± 1.2 (19.4 ± 1.3)	6.8 ± 4.6 (7.2 ± 5.8)
Clausen [41]	2016	Prospective experimental study	6 (13)	23 ± 6 (21 ± 3)	Not mentioned
Collins [48]	2006	Prospective cohort study	1173 (968) *	16.3 ± 1.1 (15.9 ± 1.3)	10.9 (13.0)
Corwin [89]	2015	Retrospective cohort study	200 (47)	14 (range= 7–18)	106 (29)
Crowe [42]	2016	Prospective cohort study	10	14.6 (range= 11–17)	30 (except 1 case)
Darling [35]	2014	Retrospective chart review	117	15.5 ± 1.6	16 ± 15
Elbin [53]	2016	Prospective cohort study	35 (34)	15.35 ± 1.73 (15.61 ± 1.65)	44.4 ± 36.0 (22.0 ± 18.7)
Field [94]	2003	Case control study	HS: 19 (20), college: 35 (18)	HS= 15.9 (range= 14–18), college= 19.9 (range= 17 – 25)	HS did not recover by 7, college recovered by 3
Gill [54]	2017	Prospective cohort study	46 (37)	19.1 ± 1.18 (18.7 ± 0.67)	21.68 ± 42.99
Henry [37]	2015	Prospective cohort study	66	16.5 ± 1.9	21 to 28
Hutchison [55]	2016	Prospective cohort study	26 (26)	21 ± 2.5	34.7 ± 37.7
Iverson [95]	2007	Prospective cohort study	114 (55 simple, 59 complex)	16.2 ± 1.2 (13 – 16)	"Simple"= 4.5 ± 2.1, "Complex"= 18.9 ± 8.6
Kontos [49]	2013	Prospective cohort study	138	15.96 ± 1.18	63% < 7 days, 37% >21
Kriz [57]	2016	Prospective cohort study	145	15.4 ± 1.5	44.5 ± 48.7
Lau [32]	2011	Prospective cohort study	107	16.02 ± 1.22	13.26 ± 9.05
Lax [96]	2015	Prospective cohort study	25	11.8 ± 1.44	20.13 ± 31.2
Lovell [97]	2003	Case control study	64 (24)	Not mentioned	Return to sport for most: 4 – 7
Lovell [59]	2007	Case control Study	28 (13)	16.6 ± 4 (18.3 ± 3.5)	33.3 ± 33.8

First Author	Year	Study Design	Sample Size (Control Sample Size)	Age in years (Controls age in years)	Time to return to sport in days (Controls return to sport time)
Lynall [60]	2016	Retrospective cohort study	34	18.38 ± 0.78	Not mentioned
Maerlender [40]	2015	Randomized control trial	13 (15)	Not mentioned	Median = 15 (median = 13)
Makdissi [61]	2010	Prospective cohort study	78	Median= 22	4.8
Maugans [81]	2012	Prospective cohort study	12 (12)	13.4 (13.4)	14
Mautner [44]	2015	Case control study	70 (70)	15.5 (15.7)	16.5 (13.5)
McClincy [62]	2006	Prospective cohort study	104	16.11 ± 2.22	63% recovered by 14 days
McDevit [98]	2015	Prospective cohort study	87	19.47 ± 6.02	55.73 ± 85.79
Mcgrath [45]	2013	Retrospective cohort study	54	15.46 ± 1.48	13.33 ± 8.87
Meehan [50]	2013	Prospective cohort study	182	15 ± 3.04	73.6% recovered in ≤28
Miller [99]	2016	Case control study	294		
Morgan [100]	2015	Case control study	40 (80)	14.9 ± 2.1 (14.8 ± 2.0)	Control recovered ≤3 weeks
Murugavel [56]	2014	Prospective cohort study	21 (21)	20.19 ± 1.03 (19.9 ± 1.67)	All were recovered 2 months post-injury
Nelson [65]	2016	Prospective cohort study	HS = 405 (89) College = 213 (61)	HS = 16.04 ± 0.99 (16.24 ± 0.73) College = 19.72 ± 1.47 (19.27 ± 1.46)	Resolved by 7 days
Newsome [66]	2016	Prospective cohort study	13 (13)	16± 1.1 (16.4 ± 1.3)	All recovered by day 30
Ono [101]	2016	Prospective cohort study	176	range= 10–18	Not mentioned
Ransom [63]	2015	Cross-sectional study	349	13.72 (range= 5 – 18)	68.8% recovered ≤28
Slobounov [84]	2007	Prospective cohort study	160	Male= 20.95, female= 21.42	All recovered by day 10
Slobounov [82]	2012	Prospective cohort study	49	range= 18 – 25	10
Terwilliger [67]	2016	Case control study	21 (21)	14.9 ± 0.89 (14.9 ± 0.89)	Not mentioned

Level of Evidence details: Level 2: evidence from one well-designed randomized control trial, Level 3: well-designed controlled trial without randomization, Level 4: well-designed case-control or cohort study, Level 6: single descriptive qualitative study.

* = Athlete exposure from 2002 to 2004

Table 2

Level of Evidence and Downs and Black Criteria Study Quality Assessment

First Author	LOE	Downs and Black Question																											Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Anzalone [91]	4	1	1	1	-	0	1	1	-	-	1	0	0	-	-	-	1	0	1	-	1	0	0	-	-	0	-	-	9
Baker [92]	4	1	1	1	-	2	1	1	-	-	1	1	0	-	-	-	0	1	1	-	1	0	1	-	-	0	-	-	13
Black [64]	6	1	1	1	-	0	1	1	-	-	1	0	0	-	-	-	1	0	1	-	1	1	0	-	-	0	-	-	10
Broglio [93]	4	1	1	0	-	0	1	1	-	-	0	0	1	-	-	-	1	0	1	-	1	1	0	-	-	0	-	-	9
Brooks [51]	4	1	1	1	-	0	1	1	-	-	0	0	0	-	-	-	1	0	1	-	1	1	0	-	-	0	-	-	9
Brown [90]	4	1	1	1	-	0	1	1	-	-	0	1	0	-	-	-	1	1	1	-	1	0	1	-	-	1	-	-	10
Buckley [47]	4	1	1	1	-	2	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	1	-	-	0	-	-	13
Clausen [41]	3	1	1	1	-	2	1	1	-	-	0	0	0	-	-	-	1	1	1	-	1	0	1	-	-	1	-	-	11
Collins [48]	4	1	1	1	-	2	1	1	-	-	1	1	1	-	-	-	1	0	1	-	1	1	0	-	-	0	-	-	13
Corwin [89]	4	1	1	0	-	0	1	1	-	-	1	1	0	-	-	-	0	1	0	-	1	1	1	-	-	0	-	-	9
Crowe [42]	4	1	1	1	-	2	1	1	-	-	1	1	0	-	-	-	1	1	0	-	1	1	1	-	-	0	-	-	12
Darling [35]	4	1	1	1	-	0	1	1	-	-	0	1	1	-	-	-	0	1	1	-	1	1	1	-	-	0	-	-	11
Elbin [53]	4	1	1	1	-	0	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	14
Field [94]	4	1	1	1	-	2	1	0	-	-	1	1	1	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	14
Gill [54]	4	1	1	1	-	0	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	0	1	-	-	0	-	-	12
Henry [37]	4	1	1	1	-	2	1	1	-	-	1	0	0	-	-	-	1	1	1	-	1	0	1	-	-	0	-	-	11
Hutchison [55]	4	1	1	0	-	0	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	0	-	-	0	-	-	11
Iverson [95]	4	1	1	1	-	2	1	1	-	-	1	0	1	-	-	-	1	1	1	-	1	1	1	-	-	0	-	-	13
Kontos [49]	4	1	1	1	-	1	1	1	-	-	1	1	1	-	-	-	1	1	1	-	1	1	1	-	-	0	-	-	13
Kriz [57]	4	1	1	1	-	2	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	0	1	-	-	0	-	-	14
Lau [32]	4	1	1	1	-	0	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	1	-	-	0	-	-	11
Lax [96]	4	1	1	1	-	1	1	1	-	-	0	1	1	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	13
Lovell [97]	4	1	1	1	-	1	1	1	-	-	1	1	1	-	-	-	1	1	1	-	1	0	1	-	-	0	-	-	12
Lovell [59]	4	1	1	1	-	1	1	1	-	-	1	1	0	-	-	-	1	0	1	-	1	0	0	-	-	1	-	-	11

First Author	LOE	Downs and Black Question																											Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Lynall [60]	4	1	1	1	-	0	1	1	-	-	1	0	0	-	-	-	0	1	1	-	1	1	1	-	-	0	-	-	10
Maerlender [40]	2	1	1	0	1	2	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1	5	25
Makdissi [61]	4	1	1	1	-	0	1	1	-	-	0	1	1	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	12
Maugans [81]	4	1	1	1	-	1	1	1	-	-	1	1	1	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	14
Mautner [44]	4	1	1	1	-	1	1	1	-	-	1	1	1	-	-	-	1	1	1	-	1	1	1	-	-	0	-	-	13
McClincy [62]	4	1	1	1	-	2	1	0	-	-	0	1	1	-	-	-	1	0	1	-	1	0	0	-	-	0	-	-	10
McDevit [98]	4	1	1	1	-	2	1	1	-	-	1	0	0	-	-	-	1	1	1	-	1	0	1	-	-	0	-	-	11
Mcgrath [45]	4	1	1	1	-	2	1	1	-	-	1	0	0	-	-	-	0	1	1	-	1	0	1	-	-	0	-	-	11
Meehan [50]	4	1	1	1	-	1	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	13
Miller [99]	4	1	1	1	-	0	1	1	-	-	1	0	0	-	-	-	1	0	1	-	1	1	0	-	-	0	-	-	10
Morgan [100]	4	1	1	1	-	1	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	1	-	-	0	-	-	12
Murugavel [56]	4	1	1	1	-	0	1	1	-	-	1	1	0	-	-	-	1	1	1	-	1	1	0	-	-	0	-	-	12
Nelson [65]	4	1	1	1	-	1	1	1	-	-	1	0	1	-	-	-	1	1	1	-	1	1	0	-	-	1	-	-	14
Newsome [66]	4	1	1	1	-	0	1	1	-	-	1	0	0	-	-	-	1	0	1	-	1	0	0	-	-	0	-	-	9
Ono [101]	4	1	1	1	-	0	0	1	-	-	0	0	0	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	9
Ransom [63]	6	1	1	1	-	1	1	1	-	-	1	1	1	-	-	-	1	0	1	-	1	0	0	-	-	0	-	-	11
Slobounov [84]	4	1	1	1	-	2	1	0	-	-	1	1	1	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	14
Slobounov [82]	4	1	1	1	-	2	1	1	-	-	0	1	1	-	-	-	1	1	1	-	1	1	1	-	-	1	-	-	14
Terwilliger [67]	4	1	1	1	-	0	1	1	-	-	1	1	0	-	-	-	1	0	1	-	1	0	0	-	-	0	-	-	10

Table 3

Definitions of Return to Sport

Article	Return to Sport Criteria	Definition of Return to Sport	Special considerations
Anzalone [91]	3 = somatic symptoms, cognitive performance and special physical exam.	A patient was cleared to begin the graduated return to play protocol after he or she had remained symptom free for a minimum of 48 hours, displayed a normal physical examination, exhibited a normal VOMS, and achieved neurocognitive testing scores that were at the patient's baseline or within normal limits.	Different recovery times for each part of the vestibulo-ocular exam.
Baker [92]	3 = somatic symptoms, cognitive performance and physical exertion test.	Recovery from sport-related concussion was self-assessment of asymptomatic or minimal symptoms (PCSS[1]= 0–6), then confirmed by computerized cognitive test (ANAM[3] or ImPACT[4]) and no symptom exacerbation on voluntary exhaustion on BCTT[2].	Only those student athletes that recovered during the 2–3 month time period were included in the analysis.
Black [64]	3 = somatic symptoms, cognitive performance and balance.	Once all concussion-related symptoms on the SCAT had resolved, athletes were allowed to attempt the ImPACT. The athlete was recovered if the ImPACT scores were considered passable by the sports medicine doctor or certified athletic trainer.	
Broglio [93]	3 = somatic symptoms, cognitive performance and balance.	Axon Sports Computerized Cognitive Assessment Tool (CCAT) for neurocognition and SCAT for symptoms were used to measure recovery following sport concussion.	Electroencephalogram was performed during auditory oddball and go/no-go tasks but no significant differences were seen between injured and controls.
Brooks [51]	2 = somatic symptoms and physical exertion test.	After resolution of clinical symptoms and signs, athletes gradually increased activity under supervision of a team physician. Athletes who remained asymptomatic throughout rehabilitation were cleared for return to play.	
Brown [90]	4 = somatic symptoms, cognitive performance, balance, and physical exertion test.	Athletes were considered recovered when they were symptom-free at rest, symptom-free with exertion and after discontinuing medicines prescribed for post-concussion symptoms, their BESS[5] scores were back to baseline where available and their computerized neurocognitive test (ImPACT) scores were at or above baseline values.	Did not include participants who recovered in less than 3 weeks. Included some participants who had concussions that were similar to sport-related concussion; for example, falling off a jungle gym.
Buckley [47]	3 = somatic symptoms, cognitive performance, and balance.	Recovery from sport related concussion was self-reported asymptomatic (GSC[6]= 0) and baseline values on ImPACT, BESS and SAC[7].	The study measured recovery from sport related concussion for those recommended rest after concussion versus those not recommended rest after concussion.
Clausen [41]	2 = somatic symptoms and physical exertion test.	Recovery was defined as self-reported asymptomatic (PCSS= 0–6) and ability to exercise to voluntary exhaustion without exacerbation of concussion symptoms on the BCTT. Secondary outcomes of recovery were recovery of cerebral blood flow velocity measured by Transcranial Doppler in the MCA[9] and exercise to exhaustion without symptom exacerbation while achieving 85% of maximal heart rate and 90% of predicted VO_2 max.	Females with PCS[8] lasting for more than 6 weeks but less than 12 weeks completed a sub-symptom threshold aerobic exercise treatment program with physiological measures before and after treatment.
Collins [48]	3 = somatic symptoms, cognitive performance and physical exertion test	All athletes needed to exhibit an asymptomatic presentation at rest and with physical exertion, as well as intact neurocognitive test performance on ImPACT	Measured the efficacy of new helmet design.
Corwin [89]	5 = somatic symptoms, cognitive performance, academic performance, physical exertion test, and special physical exam.	Both clinical and computerized neurocognitive testing (ImPACT) were used. Clinical clearance for sports participation included ability to carry full cognitive workload in school, be asymptomatic with physical exertion and have normal VOMS[10] Assessment.	The sample (200 participants) had vestibular signs after concussion whereas the controls did not have vestibular signs after concussion. Only 77% of the entire sample were sports related concussions, rest were similar injuries.

Article	Return to Sport Criteria	Definition of Return to Sport	Special considerations
Crowe [42]	2 = somatic symptoms and cognitive performance.	Return to baseline on CogSport for Kids[11]. Supplementary test= BRIEF-P and BRIEF-SR[12] and CHQ[13] were also completed on day 30. CogSport symptom scale > 7 was considered significant.	Six out of 10 participants were injured during contact sports, the remaining were injured due to falls or blows.
Darling [35]	4 = somatic symptoms, cognitive performance, balance, physical exertion test.	Recovery was defined as no or minimal symptoms (PCSS) and normalization of balance (BESS) on the SCAT-2, return to baseline on neurocognitive testing (ImPACT or ANAM) and no exacerbation of symptoms on BCTT.	This study was a retrospective chart review and follow-up via telephonic interview after two months to check for exacerbation of symptoms or difficulties with school after the return to play decision was made. Only 91 put of 117 had follow-ups.
Elbin [53]	3 = somatic symptoms, cognitive performance and physical exertion test.	Athletes were required to be symptom-free (PCSS) at rest and after physical exertion before receiving medical clearance. Athletes were also required to demonstrate neurocognitive performance (ImPACT) within normal limits (i.e., 80% confidence intervals using reliable change indices) of their own baseline scores after exertion. When symptom-free at rest, athletes were asked to schedule a clearance appointment, which included neurocognitive testing and a standardized exertion test.	
Field [94]	2 = somatic symptoms and cognitive performance	The PCSS was used to measure symptoms and a 25-minute battery of neuropsychological testing (paper-pencil tests) to measure neurocognitive ability after concussion.	
Gill [54]	4 = somatic symptoms, cognitive performance, physical exertion test and balance	Athletes had to be asymptomatic at rest and with each step of the return to play progression before returning to their sport. In addition, cognition (ImPACT) and postural stability (BESS) had to be at preinjury levels.	There was a concussed athlete group vs a non-concussed athlete group. There was also a second control group of non-athletes.
Henry [37]	3 = somatic symptoms, cognitive performance, and special physical exam.	Recovery defined as symptom free (PCSS=0), return to baseline on ImPACT, DHI[14] and vestibular-oculomotor exam except near-point convergence. Scores from DHI and vestibular-oculomotor exam were combined to form an aggregate score.	
Hutchison [55]	2 = somatic symptoms and exertion test.	Clinical recovery was defined as symptom free on Rivermead Post Concussion Symptom Questionnaire and no symptoms during the return to play protocol (exertion testing).	Other tests performed were Profile of Mood States – Short Form and Perceived Stress Scales. They were not used as a marker of recovery.
Iverson [95]	3 = somatic symptoms, cognitive performance and physical exertion test.	The athlete must not have had an ImPACT neurocognitive composite score that was significantly worse than baseline or below the 10th percentile. They also had to be asymptomatic at rest on PCSS (PCSS<7) and after light aerobic exercise.	
Kontos [49]	3 = somatic symptoms, cognitive performance, physical exertion test.	Recovery determined by a trained clinician by being symptom free at rest, back to baseline cognitive performance (ImPACT) at rest and symptom free after exertion.	The sample was divided into three groups based on post-concussion headaches and recovery time for each was given separately.
Kriz [57]	2 = somatic symptoms and cognitive performance.	PCSS was measured at initial and follow-up assessments. Pre-injury baseline (when available) and post-injury neurocognitive function was assessed with ImPACT and used in decision-making regarding return to school and return to play for injured student-athletes.	This study compared the level of physical development before and after puberty to recovery from sport-related concussion.
Lau [32]	3 = somatic symptoms, cognitive performance and physical exertion text.	Recovery was defined as clearance to return to play which was defined as asymptomatic at both rest and after exertion protocols (Zurich Guidelines), PCSS less than 7, the athlete must have had 2 ImPACT scores that were statistically lower than baseline or age-normative data and athlete's neurocognitive composite score must have been above the tenth percentile for his age.	The study sample was divided into groups based on recovery times. Rapid recovery group recovered in 4.31 ±1.74 days and protracted group recovered in 29.61 ±6.65 days.
Lax [96]	2 = somatic symptoms and cognitive exertion test.	Recovery was defined at resolution of symptoms on PCS-R[15] and then ability to perform a neurocognitive battery in one sitting without symptom exacerbation. The neurocognitive battery consisted of Children's Color Trails, Rey Auditory Verbal Learning Test, Rey	Although all these neurocognitive tests were performed, the only goal was to complete them without exacerbation of symptoms.

Article	Return to Sport Criteria	Definition of Return to Sport	Special considerations
		Complex Figure Test, Stroop Color and Word Test Children's version, Symbol Digit Modalities Test and verbal fluency component of NEPSY-II[16].	
Lovell [97]	2 = somatic symptoms and cognitive performance.	Recovery was monitored using ImPACT's PCSS and neurocognitive testing.	Only mild concussions were included in this study (i.e, no loss of consciousness)
Lovell [59]	3 = somatic symptoms, cognitive performance and physical exertion test.	For an athlete to be recovered, all ImPACT composite scores were required to be above baseline levels or within the normal range and athletes had to be asymptomatic at rest and during graduated aerobic exercises.	fMRI was also done and compared with clinical recovery.
Lynall [60]	4 = somatic symptoms, cognitive performance, balance and special physical exam.	After concussion, the athlete has to complete a clinical battery of tests including computerized neurocognitive testing, graded symptom checklist (both part of CNS Vital Signs) and SOT[17] and these results had to be comparable to baseline values. Recovery was complemented by a thorough clinical exam by physician. Additional testing may be conducted if requested by the physician.	This study tried to see if there were any difference in preseason baseline testing scores before and after a concussion hence they described the time from recovery to next preseason baseline.
	3 = somatic symptoms, cognitive performance, and balance.	When ImPACT, balance and symptoms (PCSS) had returned to baseline, the athlete was determined to be recovered. Exercise intolerance was also measured in this study but was not a criterion for recovery.	Method of assessing balance was not specified. This randomized control trial evaluated the efficacy of moderate physical exercise on a bike versus rest as a treatment modality after acute concussion.
Makdissi [61]	3 = somatic symptoms, cognitive performance and physical exertion test.	Clinical recovery was defined as return to full training or competitive play, it included symptom resolution both at rest and exertion, and recovery of cognitive function (DSST[18], TMT-B[19]). The team doctor also had to make the return to play decision. CogSport was also used to measure cognitive recovery, but due to time and resource limitations, not all teams were able to use it as part of the testing protocol.	
Maugans [81]	4 = somatic symptoms, cognitive performance, physical exertion test and cerebral blood flow.	Clinical recovery was defined as symptom resolution on the ImPACT, return to normal physical and cognitive activity. Recovery of cerebral blood flow was defined as return to control values. MRI[20] and H-MRS[21] were performed during this study, but were not statistically significant and were not used to measure clinical recovery.	27% of patients recovered cerebral blood flow within 14 days and > 64% after 30 days but clinical recovery was within 14 days.
Mautner [44]	2 = somatic symptoms and cognitive performance.	Post-concussion recovery was defined as a return to equivalent baseline neurocognitive score on ImPACT and concussion symptom score of less than or equal to 7.	In this study, patients with self-reported ADHD plus sport-related concussion were compared to controls without ADHD but with sport-related concussion.
McClincy [62]	3 = somatic symptoms, cognitive performance and physical exertion test.	To determine when an athlete was completely recovered from concussion, their post-concussion data were compared to their baseline data. All athletes diagnosed with an in season concussion did not return to play until they were symptom free at rest and with exertion and their ImPACT data had returned to baseline levels.	On day 14, only verbal memory scores were significantly different from baseline.
McDevit [98]	4 = somatic symptoms, cognitive performance, balance and special physical exam.	Full return to play was determined by treating physician which included objective screening (including vestibular-ocular assessments), balance (BESS) and ImPACT. Gene testing for GRIN2A promoter polymorphs was also done to see if it would have any correlation to recovery time.	This study tested the relationship of the gene and the duration of post concussive symptoms.
Mcgrath [45]	2 = somatic symptoms and cognitive performance.	The athletic trainer made the decision that participant was symptom free (this does not mean PCSS=0), ImPACT scores returned to baseline at rest. After the patients were symptom free at rest, they participated in a physical exertion protocol and neurocognitive tests were retested. This did not affect the already made diagnosis of clinically recovered.	The participants were classified as post physical exertion neurocognitive test pass or fail.
Meehan [50]	4 = somatic symptoms, cognitive performance, balance and physical exertion test.	Recovery is defined as symptom free (PCSS=0) at rest and exertion after discontinuing any medication for post concussive symptoms, ImPACT scores at or above baseline, BESS at baseline. Baseline score were not available for majority of the participants, so they were compared to age normative date.	

Article	Return to Sport Criteria	Definition of Return to Sport	Special considerations
Miller [99]	2 = somatic symptoms, balance and physical exertion test	Recovery was defined as patients who were free of symptoms on the SCAT2 both at rest and with exertion.	Participants injured in motor sports like motocross were also included.
Morgan [100]	2 = somatic symptoms and physical exertion test.	The controls were defined as recovered by clearance from a trained health care provider of symptom resolution (PCSS) at rest and exertion. They did not use the Likert Scale on the PCSS, instead scored them as present or absent.	In this study, the controls were the ones who recovered from a concussion within 3 weeks and the study sample developed PCS.
Murugavel [56]	3 = somatic symptoms, cognitive performance and physical exertion test.	Athletes were cleared to return to full contact play once they were symptom free at rest, had successfully completed the exertional program and were neurocognitively functioning at baseline levels on ImPACT.	
Nelson [65]	3 = somatic symptoms, cognitive performance and balance.	Recovery was defined in two ways: (1) GSC, BESS, SAC and traditional paper-pencil neurocognitive tests at each baseline and post-injury time point to look for evidence of differential recovery patterns across high school and collegiate athletes, and (2) compared concussed athletes (for high school and collegiate groups separately) with uninjured control participants at each time point.	
Newsome [66]	2 = somatic symptoms and cognitive performance.	Resolution of post-concussion symptoms, recovery of cognitive performance on ImPACT to preseason level, and clearance by a licensed health provider to return to play by day 30 post-injury.	After the athlete was recovered, functional connectivity was assessed 1 month after sport-related concussion.
Ono [101]	2 = somatic symptoms and cognitive performance.	Recovery was measured as the number of days to return to baseline neurocognitive and symptom scores on ImPACT	
Ransom [63]	2 = somatic symptoms and cognitive performance.	Recovered participants were those that had no elevation of symptoms on PCSI[22] (was adjusted by subtracting post injury scores by baseline scores) and no impairment on neurocognitive testing (age 5–12 used Multimodal Assessment of Cognition and Symptoms for Children and age 13–18 used ImPACT). Participants and their parents also completed the CLASS[23] to measure post injury academic experiences but that was not part of the recovery criteria.	The participants were labeled as recovered or not on average of 28th day from their concussion based on the tests.
Slobounov [84]	2 = somatic symptoms and cognitive performance.	All patients were cleared for sport participation 10–15 days post-injury. Postural responses to visual field motion in a virtual reality environment were recorded up to 30 days after concussion.	Despite clinical recovery, all athletes had persistent abnormalities of balance (incoherence with visual field motion responses) during a "moving room" condition displayed on a virtual reality device, consistent with subtle ongoing abnormal postural control. Postural control was significantly worse and took longer to recover in those suffering a second concussion during the study period.
Slobounov [82]	2 = somatic symptoms and cognitive performance.	All the athletes were cleared for sports participation based on Subjective Symptom Rating scale, DSST[18], and Trails "B" Test. EEG[24] was done on day 7, 15, 30, 6 months and 12 months but did not contribute to the return to play decision.	
Terwilliger [67]	4 = somatic symptoms, cognitive performance, balance and academic performance.	Date of recovery was determined by clinician based on child and parent report of the resolution of symptoms (PCSI-SR13 and PCSI-P) plus cognition, balance, and school performance having returned to normal functioning.	They divided the participants into single and repeat injury groups and measured the difference in their return to play time.

[1] PCSS= Post Concussion Symptom Scale, part of the Sport Concussion Assessment Tool (SCAT)[71] and ImPACT.

[2] BCTT= Buffalo Concussion Treadmill Test,[102] a progressive, graded treadmill test which leads to voluntary exhaustion.

[3]ANAM= Automated Neuropsychological Assessment Metrics,[74] a computerized neurocognitive test.

[4]ImPACT= Immediate Post-concussion Assessment and Cognitive Test,[43] a computerized neurocognitive test.

[5]BESS= Balance Error Scoring System,[103] a test for static balance also part of the SCAT.

[6]GSC= Graded Symptom Checklist,[104] a 17 item Likert style symptom list promoted by the National Athletic Trainer Association.

[7]SAC= Standard Assessment of Concussion,[105] a standardized onsite tool for checking concussion symptoms.

[8]PCS= Post-Concussion Syndrome.

[9]MCA= Middle Cerebral Artery.

[10]VOMS= Vestibular/Ocular Motor Screening Assessment, a standardized concussion screening assessment validated by the University of Pittsburg.[106]

[11]CogSport for Kids= A computerized neurocognitive test with includes a post-concussion symptom checklist (PCSC).[75]

[12]BRIEF-P/SR= Behavioral Rating Inventory of Executive Function – Parent/Self-Report[107] is a measure to assess executive function in day to day environments for ages 12 and greater.

[13]CHQ= Child Health Questionnaire[108] is a measure of functional health status and well-being.

[14]DHI= Dizziness Handicap Inventory,[109] a measure to assess general dizziness.

[15]PCS-R= Post Concussion Symptom Scale-Revised,[110] a 22 item self-report symptom questionnaire with a Likert scale.

[16]NEPSY-II= Developmental Neuropsychological Assessment Second Edition,[111] a comprehensive neuropsychological battery designed to create neuropsychological profiles for children.

[17]SOT= Sensory Organization Test performed on the NeuroCom Smart Balance Master.[112]

[18]DSST= Digit Symbol Substitution Test.

[19]TMT= Trail Making Test. CNS Vital Signs= A computerized neurocognitive test which includes a graded symptom checklist.[76]

[20]MRI= Magnetic Resonance Imaging.

[21]H-MRS= Hydrogen Magnetic Resonance Spectroscopy.

[22]PCSI= Post-Concussion Symptom Inventory,[113] a self-report form for concussion symptoms.

[23]CLASS= Concussion Learning Assessment and School Survey,[63] a tool to measure post injury academic experiences.

[24]EEG= Electroencephalogram.

Table 4

Frequency of Recovery Criteria

Recovery Criteria	Number of Studies	Studies
Somatic symptoms and cognitive performance	11	4244455763668284949710 1
Somatic symptoms and physical exertion test	4	415155100
Somatic symptoms and cognitive exertion test	1	96
Somatic symptoms, cognitive performance and physical exertion test	10	32484953565961629295
Somatic symptoms, cognitive performance and balance	5	40476593114
Somatic symptoms, cognitive performance and special physical exam	2	3791
Somatic symptoms, cognitive performance, balance and physical exertion test	4	35505490
Somatic symptoms, cognitive performance, balance and special physical exam	2	6098
Somatic symptoms, cognitive performance, balance and return to learn	1	67
Somatic symptoms, cognitive performance, physical exertion test and cerebral blood flow	1	81
Somatic symptoms, cognitive performance, physical exertion test, special physical exam and return to learn	1	89
Somatic symptoms, balance and physical exertion test	1	99

Table 5

Methods of post-recovery follow-up and conclusion

First author	Method of post-recovery follow-up	Conclusion
Crowe [42]	On day 30 when the athletes were recovered (except 1), the BRIEF-P/SR and CHQ were completed to measure executive function in day to day environments and functional health status and well-being respectively.	The questionnaires did not identify persistent impairments in the participants after recovery had taken place, with majority of the results falling in normal range.
Darling [35]	A structured telephone follow-up interview of the athletes was conducted a minimum of 2 months after they were cleared for return to play. The interview asked about difficulty in school after they returned and presence of concussion symptoms.	All had successfully returned to sport without recurrent symptoms. 38.5% of the athletes reported new or increased problems in school, mainly decreased ability to concentrate, but the timing of cognitive symptoms was not assessed (may have been during natural recovery phase).
Lynall [60]	Repeat baseline testing was performed on the athletes 169.5 (range 37–333) days after last post-injury test. Repeat baseline testing included computerized neurocognitive testing, balance testing and a graded symptom checklist. Scores in repeat baseline testing were compared with original pre-season baseline testing.	There is limited usefulness for repeat baseline testing in concussion management. It is time consuming and costly and has no significant difference to original pre-season baseline scores.
Maugans [81]	Although not included in the criteria for recovery, MRI, diffusion tensor imaging, H-MRS and phase contrast angiography was performed at days 3, 14 and 30 post-injury.	There was no evidence of structural or metabolic injury in MRI or H-MRS. In 36% of the participants the CBF values had not normalised by day 30 post-injury.
McGrath [45]	Post exertion ImPACT testing was done after recovery and compared with baseline pre-injury ImPACT scores.	27.7% of the concussed student athletes who were determined to be recovered exhibited cognitive decline following moderate physical exertion.
Newsome [66]	Functional connectivity was measured 1 month post-sport-related concussion in athletes who were cleared to return to play using the Hopkins Verbal Learning Test during fMRI.	The injured and control groups did not differ in verbal memory after 1 month but differed in functional connectivity.
Slobounov [84]	Postural sway was assessed using a virtual reality device that displayed a “moving room” condition on day 30.	Balance problems (trunk sway during the “moving room” condition) persisted 30 days after injury, indicating that symptom and cognitive recovery did not coincide with balance recovery. Balance problems persisted significantly longer in those sustaining two concussions within 30 days when compared with a single concussion.
Slobounov [82]	EEG was performed alongside the measures used to determine recovery at day 7, 15 and 30 and months 6 and 12. EEG was recorded while sitting, standing on a force plate and then on a foam base of support with eyes open/closed conditions.	There was no significant change in neurological assessment and symptoms after the return to play decision was made but 85% of those who showed suppression in the acute phase did not return to pre-injury baseline up to 12 months post injury.