Rest and exercise early after sport-related concussion: a systematic review and meta-analysis

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ABSTRACT

Objective To synthesise the evidence regarding the risks and benefits of physical activity (PA), prescribed aerobic exercise treatment, rest, cognitive activity and sleep during the first 14 days after sport-related concussion (SRC).

Design Meta-analysis was performed for PA/prescribed exercise interventions and a narrative synthesis for rest, cognitive activity and sleep. Risk of bias (ROB) was determined using the Scottish Intercollegiate Guidelines Network and quality assessed using Grading of Recommendations, Assessment, Development and Evaluations.

Data sources MEDLINE, Embase, APA PsycInfo, Cochrane Central Register of Controlled Trials, CINAHL Plus and SPORTDiscus. Searches were conducted in October 2019 and updated in March 2022.

Eligibility criteria Original research articles with sport-related mechanism of injury in >50% of study sample and that evaluated how PA, prescribed exercise, rest, cognitive activity and/or sleep impact recovery following SRC. Reviews, conference proceedings, commentaries, editorials, case series, animal studies and articles published before 1 January 2001 were excluded.

Results 46 studies were included and 34 had acceptable/low ROB. Prescribed exercise was assessed in 21 studies, PA in 15 studies (6 PA/exercise studies also assessed cognitive activity), 2 assessed cognitive activity only and 9 assessed sleep. In a meta-analysis of seven studies, PA and prescribed exercise improved recovery by a mean of −4.64 days (95% CI −6.69, −2.59). After SRC, early return to light PA (initial 2 days), prescribed aerobic exercise treatment (days 2–14) and reduced screen use (initial 2 days) safely facilitate recovery. Early prescribed aerobic exercise also reduces delayed recovery, and sleep disturbance is associated with slower recovery.

Conclusion Early PA, prescribed aerobic exercise and reduced screen time are beneficial following SRC. Strict physical rest until symptom resolution is not effective, and sleep disturbance impairs recovery after SRC.

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WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ An initial period of relative rest after sport-related concussion (SRC) may be important based on expert consensus.
- ⇒ Excessive physical activity or exercise early after SRC can temporarily exacerbate symptoms.
- ⇒ Excessive cognitive activity early after SRC can temporarily exacerbate symptoms.

WHAT THIS STUDY ADDS

- ⇒ Strict rest until symptom resolution is not effective for SRC.
- ⇒ Light-intensity physical activity (eg, walking that does not more than mildly exacerbate symptoms) during the 48 hours after SRC facilitates recovery.
- ⇒ Prescribed subsymptom threshold aerobic exercise treatment, based on systematic exercise testing that identifies the individual's mild symptom exacerbation heart rate threshold, can safely be started within 2–14 days of SRC, facilitates recovery and reduces the incidence of postconcussive symptoms persisting beyond 1 month from injury.
- ⇒ Sleep disturbance appears to impair SRC recovery.
- ⇒ Reducing time spent viewing screens (eg, phones, computers) during the first 48 hours after injury appears to facilitate recovery.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ Clinicians should no longer reccomend strict or prolonged physical and cognitive rest ("cocooning") for the managment of SRC.
- ⇒ Clinicians should encourage athletes to engage in light physical and cognitive acitivity but to limit usual screen time within the first 48 hours of injury.
- ⇒ Clinicians can consider prescribing individualised heart rate-based aerobic exercise treatment to reduce the risk of symptoms persting >1 month.
- ⇒ Clinicians should advise athletes that brief, mild symptom exacerbation (no more than a 2 point increase on a 0-10 scale compared with the pre-activity level) during physical or cognitive acitivy does not delay recovery.
- ⇒ More research is needed on the effects of early cognitive acitivity and sleep quality for SRC recovery.

INTRODUCTION

The first four Concussion in Sport Group (CISG) statements on sport-related concussion (SRC), based largely on early animal research and expert opinion, recommended patients undergo strict cognitive and physical rest until the acute symptoms resolve.[1–4] The fifth CISG statement (Berlin 2016),[5] however, concluded that there was insufficient evidence to support prolonged strict rest and instead recommended a short period of 24–48 hours of relative rest.

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Early studies suggested that a moderate amount of activity after concussion was beneficial.[6–9] Subsequent preclinical studies suggested that the timing (early vs late) and nature (voluntary vs forced) of exercise, as well as individual factors (injury severity, preinjury activity level), affected recovery.[10–14] These studies suggested that early voluntary exercise was beneficial in rats with mild traumatic brain injury and in those with greater preinjury physical activity (PA). As of the fifth CISG statement, however, there was little scientific evidence in humans to support the effectiveness and specific timing, amount, duration, and progression of rest, PA, cognitive activity or prescribed exercise after SRC.[9 15]

Up to 30% of adolescents experience persisting postconcussive symptoms (PPCS) beyond 1 month,[16 17] which impairs participation in school, PA and overall quality of life.[18 19] There is opportunity to treat SRC early after injury to facilitate recovery and reduce PPCS risk. The purpose of this systematic review (SR) was to address two questions: (1) which activity management strategies should be incorporated into the early (≤14 days from injury) recovery phase (eg, rest, exercise, sleep), and (2) when should PA, prescribed exercise and cognitive activity be started and how should they be progressed?

METHODS

The search strategy focused on three concepts: concussion/head impacts, sports and rest/exercise. Search strategy development is outlined in the methodology paper for the sixth CISG.[20] The MEDLINE search was pilot tested against seed and relevant studies from the fifth CISG statement.[5] The final MEDLINE search was then translated to all databases. Search records were uploaded to Covidence for deduplication and screening. This review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.[21] The completed PRISMA checklist and full search strategies are available in the supplementary files.

The following databases were searched: MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations and Daily (Ovid), Embase (Ovid), APA PsycInfo (Ovid), Cochrane Central Register of Controlled Trials (Ovid), CINAHL Plus with Full Text (EBSCO) and SPORTDiscus with Full Text (EBSCO). Searches were originally run in October 2019 and updated in March 2022.

A rapid screen (single reviewer), title/abstract screen (including inter-rater agreement) and full text screen were performed as outlined in the methodology paper.[20] All titles/abstracts and full texts were screened independently by two reviewers (JJL, JSB, CMT and KJS). Where applicable, a third blinded reviewer settled any discrepancies. Inclusion criteria were (1) original research articles (ie, randomised controlled trials (RCT), quasi-experimental designs, cohort and case–control studies), (2) mechanism of injury >50% SRC in study sample and (3) evaluated how PA, prescribed aerobic exercise, rest, cognitive activity and/or sleep impact recovery following SRC. Review articles, conference proceedings, commentaries, editorials, case series, animal studies, articles published before 1 January 2001 and non-English studies were excluded.

Data extraction and risk of bias (ROB) assessments were completed independently by two authors using the Scottish Intercollegiate Guidelines Network (SIGN) checklists (RCT, cohort and case–control designs) that were adapted to meet the purpose of the SRs on concussion.[20] According to SIGN criteria, studies were rated as high quality, acceptable or inadmissible based on methodological rigour. A third rater was engaged in case of discrepancy. Standardised tables were created a priori to extract the following data: year, study design, location and duration; participants (sample size, sex, age, mechanism of injury, sport and level of sport); inclusion and exclusion criteria; definition of concussion; intervention (type, frequency, duration, intensity); outcome measures; main findings; and level of evidence.

A meta-analysis was completed for high-quality and acceptable studies that compared PA/prescribed aerobic exercise treatment to treatment as usual (TAU), to stretching exercise or to resting controls, and whose primary outcome was days to symptom resolution. As the outcome was similar across studies, weighted mean differences (95% CIs) were calculated for each study and pooled using random effects weighting. Pooled estimates were visualised using forest plots and heterogeneity was quantified through the I^2 statistic to determine whether variation across studies was due to actual between-study differences versus chance.[22] A Grading of Recommendations, Assessment, Development and Evaluations (GRADE) was completed for all studies within each of the five review domains (PA, prescribed exercise, rest, cognitive activity and sleep).[23] The summary of findings/pooled estimates in the GRADE table combined the PA and prescribed exercise studies that had control groups as well as the same outcome measure (days until symptom free). Given the heterogeneity of the interventions and outcomes for the rest, cognitive activity and sleep studies, a narrative synthesis was completed. Stata IC (V.15) was used for all analyses. Alpha was set a priori at 0.05.

Statement of equity, diversity and inclusion

The 13 expert panellists represent multiple disciplines from four different countries (Australia, Canada, Ireland and the USA) and four are women. None, however, identified as non-white. Most are senior clinicians and researchers across multiple areas of expertise, but several early career researchers are involved as methods authors and coauthors. Although more diverse than previous consensus processes, the need for greater geographical and demographic diversity and inclusion has been identified by the Scientific Committee, and a postconference survey was conducted among the Expert Panel to help determine equity, diversity and inclusion focus areas.

RESULTS

A total of 11 078 citations were identified and 4871 duplicates were removed. The rapid screen excluded 4310 clearly irrelevant records. Two records were identified through reference searching. Following title and abstract screening, 1817 more records were removed, and 83 full texts were reviewed. Thirty-seven studies were excluded for the following: wrong interventions (n=10), duplicate (n=9), wrong outcome (n=7), wrong study design (n=4) and wrong publication type (n=7). Forty-six studies met the inclusion criteria (figure 1). Following quality assessment by two authors, 12 studies with unacceptable ROB were included but were not used to inform the domain recommendations. Therefore, the recommendations were developed based on the 34 articles with acceptable or low ROB (figure 2).

A total of 9432 participants (40% female; aged 5–33 years) were included (online supplemental table 1). Seven studies (15%) were conducted in Canada, one in both Canada and the USA (2%) and the rest (83%) were from the USA. Of the included studies (12 RCTs, 17 prospective cohort studies, 12 retrospective cohort studies and 5 pre-experimental and quasiexperimental studies), four RCTs and two prospective studies were 'high-quality'. Prescribed exercise was assessed in 21 (46%) studies, PA in 15 (33%) studies (6 PA/exercise studies also assessed cognitive

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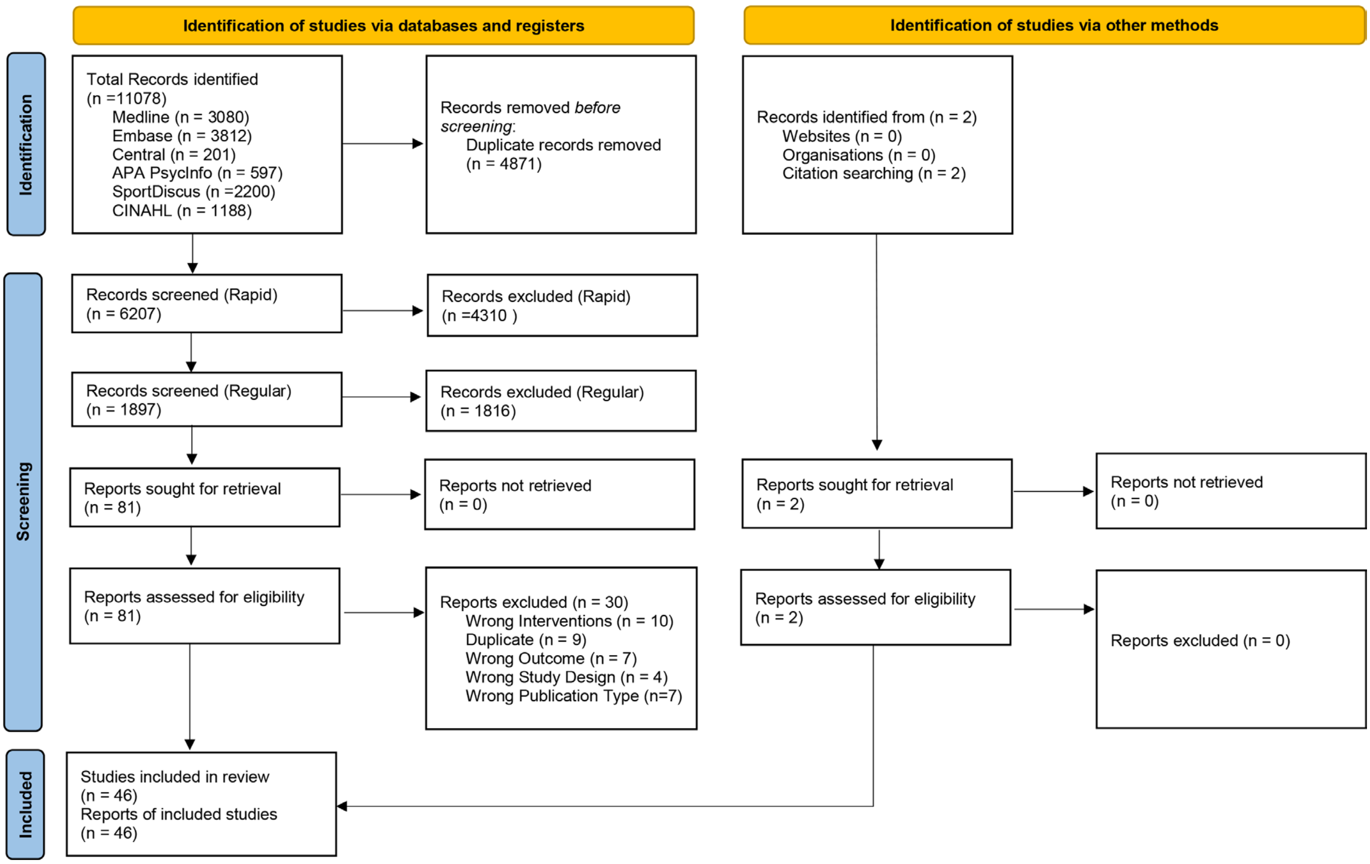

Figure 1 Modified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 flow diagram for systematic reviews that includes searches of databases, registries and other sources.[21]

activity), 2 (4%) assessed cognitive activity only and 9 (20%) assessed sleep (figures 2 and 3).

PA after SRC

When compared with strict rest or no PA, the best evidence supports the safety, tolerability and efficacy of early (within days of injury) light to moderate levels of PA for facilitating recovery and reducing PPCS incidence in symptomatic adolescents after SRC.

An *acceptable-quality* retrospective study[7] assigned adolescents after SRC to one of five groups based on a postinjury activity intensity scale. Those with high levels of combined cognitive and PA (eg, school activity and a sports practice or game) had worse symptoms and neurocognitive performance while moderate levels of both (eg, slow jogging or mowing the lawn) had better performance. An *acceptable-quality* retrospective cohort study[24]

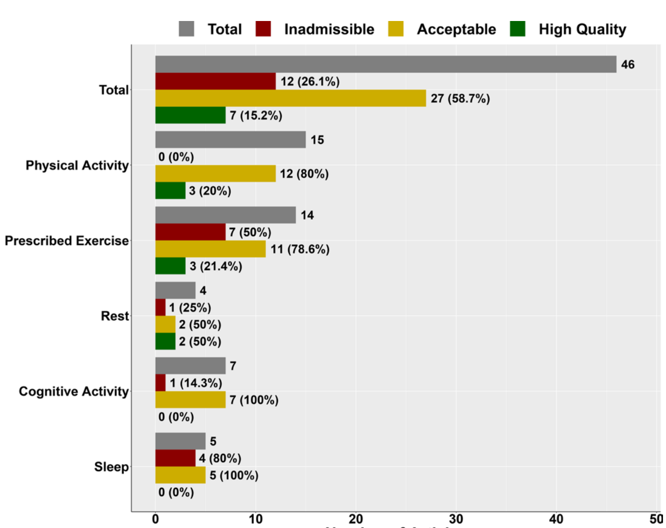

Figure 2 Risk of bias assessments using the Scottish Intercollegiate Guidelines Network checklist for all included studies according to the five domains. Some studies were included in multiple domains, thus the total across the five domains exceeds the total number of studies (46).

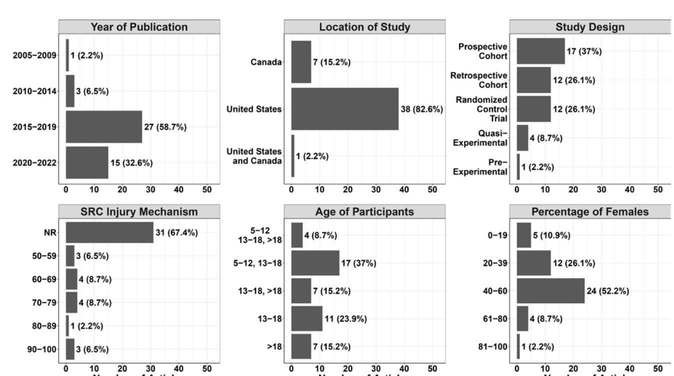

Figure 3 Study demographics and characteristics for the included articles. The not reported (NR) studies under the sport-related concussion (SRC) injury mechanism panel contain participants who sustained their concussions in sport or during activities with similar mechanisms; however, the percentage was not reported.

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of self-reported early PA versus no PA in paediatric (aged 8–18) athletes found that the no-PA group took significantly longer to recover (median 16 (IQR=8, 24) vs 10.5 days (IQR=4, 17); p=0.02). An *acceptable-quality* retrospective cohort study[25] stratified groups into 'no/low' and 'moderate/high' exercise. Moderate/high group recovered 21 days faster (95% CI −27.07, −15.48; p<0.001). An *acceptable-quality* retrospective analysis of a prospective cohort study[26] grouped paediatric athletes into 'early' and 'no' PA groups. Early-PA group recovered faster (15.6±12.4 vs 27.2±24.2 days), returned to play (RTP) faster (24.2±15.7 vs 36.7±40.6 days) and less often experienced PPCS (22% vs 44%).

An *acceptable-quality* prospective cohort study[27] of US collegiate athletes found that those reporting PA (eg, walking, light sport activity, partial team practice) within 48 hours of SRC recovered faster and had earlier RTP than those reporting early mental activity (eg, no or some class attendance, homework). An *acceptable-quality* prospective cohort study[28] showed that those who took fewer steps/day, exercised fewer days/week and exercised fewer total minutes/week were more likely to RTP beyond 28 days. Optimal cut points distinguishing the groups were ≥10 251 average steps/day, ≥4 exercise sessions/week and exercising ≥134 total min/week. An *acceptable-quality* prospective cohort study of self-paced PA (accelerometer) and cognitive activity (self-report)[29] showed that every 2000 increase in step count during the first postinjury week was associated with faster symptom resolution (HR 1.17; 95% CI 1.02–1.34); however, it was not significant after adjusting for average symptom severity score. Each 60 min increase in school attendance time during the first postinjury week was associated with faster symptom resolution.

A *high-quality* prospective cohort study from paediatric emergency departments (EDs) found that retrospectively reported PA (mostly light aerobic and sport-specific exercise) during the week after injury was associated with a significantly lower PPCS incidence at 28 days (28.7%) versus those reporting no first week PA (40.1%).[6] A *high-quality* prospective RCT from EDs[30] assigned participants within 48 hours of injury to incremental resumption of non-contact PA beginning 72 hours after injury (even if symptomatic) versus advice to rest and return to PA once asymptomatic (control group). An intention-to-treat (ITT) analysis did not show a significant effect of early PA on recovery, but a per-protocol analysis of adherent participants showed that the early-PA group had fewer symptoms versus controls at 2 weeks (mean difference −4.3 (95% CI −8.4 to −0.2); p=0.038) and less often experienced symptoms beyond 12 days.

Prescribed aerobic exercise treatment early (within 14 days) of SRC

When compared with advice to rest or to placebo-like stretching programmes, the best evidence supports the safety, tolerability and efficacy of early (within 2–14 days of injury) prescribed aerobic exercise treatment for facilitating recovery and reducing PPCS incidence in symptomatic athletes after SRC. The strongest evidence is for subsymptom threshold aerobic exercise based on determination of the individual's level of exercise tolerance on systematic exercise testing.

An *acceptable-quality* retrospective cohort study[31] found that aerobic exercise (self-initiated or physician prescribed) started 3, 5, 7 and 14 days after injury was associated with a respective 36.5% (HR 0.63; 95% CI 0.53–0.76), 59.5% (HR 0.41; 95% CI 0.28–0.58), 73.2% (HR 0.27; 95% CI 0.16–0.45) and 88.9% (HR 0.11; 95% CI 0.06–0.22) prolonged time to return to sport (RTS) versus initiating exercise within 1 day of SRC (p<0.001). An *acceptable-quality* retrospective study[32] of early (<16 days from injury) supervised (in-clinic) aerobic versus non-early supervised aerobic exercise (≥16 days from injury) showed that early exercise participants were cleared for RTS sooner (26.5±11.2 vs 35.1±26.5 days; p=0.02). This study was limited, however, by lead-time bias with earlier access to supervised exercise in the early cohort. An *acceptable-quality* quasiexperimental study[33] of prescribed subsymptom heart rate threshold (HRt) aerobic exercise (mean 5 days from injury) versus advice to rest in males reported significantly faster recovery from the date of the first clinic visit for the exercise group (8.29±3.85 vs 23.93±41.73 days; p=0.048). An *acceptable-quality* small RCT[34] showed that a generic submaximal aerobic exercise prescription (beginning with 10 min of cycling at 50% of age-predicted maximal HR) was safe and feasible within the first week of SRC, although it was underpowered to show a treatment effect versus TAU. A *high-quality* prospective study[35] showed that adolescent hockey players who did moderate to vigorous PA (MVPA by actigraphy, not guided by individualised HRt treatment) in the 3 days after SRC took significantly longer to RTP (p=0.041) versus players who did less MVPA.

An *acceptable-quality* prospective RCT[36] found that athletes who reported exercising ≥100 min/week during the first month after SRC recovered faster than those who reported exercising <100 min/week, despite similar initial symptom scores. A *high-quality* prospective multicentre RCT[37] found that adolescents within 10 days of SRC prescribed aerobic exercise based on their individual HRt recovered faster (median 13 days (IQR: 10–18.5)) versus a placebo-like stretching programme (median 17 days (IQR: 13–23); p=0.009). A *high-quality* prospective multicentre RCT[38] of individualised aerobic exercise versus placebo-like stretching initiated 24 hours to 10 days after SRC used an ITT methodology and reported almost identical results: aerobic exercise group recovered in 14 (IQR: 10–25) vs 19 days (IQR: 13–31) for stretching exercise group. Those who best adhered to aerobic exercise recovered even faster (median 12 (IQR: 10–22) vs 21 days (IQR: 13–35); p=0.011). Importantly, there was a 48% reduction in PPCS incidence for the early aerobic exercise group (HR for stretching vs aerobic exercise=0.52 (95% CI 0.28–0.97); p=0.039).

Prescribed exercise for PPCS

The best evidence supports that prescribed subsymptom threshold aerobic exercise treatment is effective for facilitating recovery in adolescents with symptoms persisting beyond 1 month after SRC.

An *acceptable-quality* pilot RCT[39] evaluated a 6-week daily home aerobic exercise programme (Subthreshold Exercise Program, STEP) versus a control stretching programme (handout, 5–10 min daily) in adolescents with PPCS. Exercise intensity was 80% of the HRt on the Buffalo Concussion Treadmill Test (BCTT), and duration began at 5–10 min/day and was increased weekly 5–10 min/day via phone (goal=60 min/day). STEP significantly improved recovery from PPCS versus stretching (p=0.02). An *acceptable-quality* exploratory RCT[40] evaluated subsymptom threshold cycling versus a stretching programme in adolescents with PPCS. Beginning at week 1, aerobic exercise group recovered faster (p=0.044). An *acceptable-quality* RCT[41] compared 6 weeks of TAU (symptom management and RTP advice, return-to-school facilitation and physiatry consultation) with active rehabilitation in adolescents with PPCS (TAU plus in-clinic subsymptom threshold aerobic training, coordination

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exercises and visualisation and imagery techniques guided by a physical therapist). In-clinic symptom exacerbations occurred in 30% of aerobic training sessions but resolved within 24 hours. Active rehabilitation was associated with faster recovery versus TAU.

When should PA and prescribed exercise be started after SRC and how should they be progressed?

The best evidence supports that PA and prescribed aerobic exercise treatment can be started as soon as 1 day (PA) and 2 days (prescribed exercise) after SRC in symptomatic athletes. Aerobic exercise can safely be progressed systematically based on repeat exercise testing in a supervised environment (every few days to every week). Athletes without access to exercise testing can advance exercise according to the degree of symptom exacerbation experienced during the prior exercise bout.

An *acceptable-quality* retrospective cohort study[31] reported that either self-initiated or physician-prescribed aerobic exercise as soon as within 1 day of SRC was associated with faster recovery than when initiated 3, 5, 7 or 14 days after SRC. A *high-quality* RCT[42] found that symptomatic athletes performing the BCTT as early as 2 days after SRC did not increase symptoms within 24 hours or experience delayed recovery when compared with those who did not do the test. Two *high-quality* RCTs[37 38] found that individualised aerobic exercise, prescribed a mean of 4.9±2.3 and 5.9±2.3 days after SRC, respectively (range: 1–10 days), safely facilitated recovery.

No experimental studies specifically examined the optimal amount and progression of exercise. There is, however, guidance from recent literature. The aerobic exercise prescription can safely be adjusted and progressed by establishing a new symptom-exacerbation HRt on systematic exercise testing performed every few days to every week.[37–39 43] Patients without access to exercise testing can start at 50% of their age-appropriate maximum HR (220−age) for 15–20 min and systematically advance the training target HR according to the degree of symptom exacerbation experienced during the prior exercise bout.[44] Finally, in a secondary analysis of one arm of an RCT,[45] adolescent athletes who best adhered to the prescription within the first 2 weeks (performing >2/3 of their prescribed exercise sessions, confirmed by HR monitor data) recovered faster than those who were not as adherent (median recovery time 12 (IQR: 9–22) vs 21.5 days (IQR: 13–30); p=0.016), despite being more symptomatic and more exercise intolerant at their initial visit.

Rest after SRC

The best evidence supports that strict rest in the initial days after injury is not effective for facilitating recovery in adolescents and young adults after SRC.

An *acceptable-quality* retrospective cohort study[46] reported that athletes given a non-specific recommendation for cognitive rest after SRC took longer to recover versus those who were not (57 vs 29 days; p<0.01). After adjusting for covariates, however, only initial symptom score was associated with symptom duration. An *acceptable-quality* retrospective study[47] compared three cohorts of male and female adolescents after SRC: one was advised to rest (eg, no sports or other forms of exercise, limit activities such as using smartphones, but do not stay in a dark room or avoid social interaction); one was prescribed individualised aerobic exercise 20 min/day; and one received a placebo-like stretching programme for 20 min/day (gentle breathing and whole body stretching exercises). The difference between resting HR and the HRt on the BCTT correlated with recovery duration in the rest (p=0.012) and placebo stretching groups (p=0.011) but not in aerobic exercise group, suggesting a beneficial effect of aerobic exercise on recovery. In an *acceptable-quality* quasiexperimental trial[48] using the same participants, rest group recovery was significantly delayed when compared with aerobic exercise (16 (IQR: 9.25–23.25) vs 13 days (IQR: 10–18.5); p=0.020).

An *acceptable-quality* prospective cohort study[49] reported that an initial period of physical inactivity until the first physician examination was not associated with symptom duration after concussion. In the adolescent participants, greater PA after injury was associated with faster recovery (HR 1.0018, 95% CI 1.000–1.003). An *acceptable-quality* prospective cohort study[50] found that most participants reported adherence to treatment recommendations after SRC; however, adherence to different types of rest (physical, mental with restrictions from electronics and mental with restrictions from school) more often *delayed recovery* versus those who rarely followed recommendations (univariate Poisson regression estimate range: −0.23 to −0.52). A *high-quality* RCT[9] randomised ED patients (11–22 years) to a recommendation for strict rest for 5 days versus TAU (1–2 days of rest followed by stepwise return to activity). The strict rest group reported more daily concussion symptoms over 10 days (p<0.03) and slower symptom resolution versus TAU.

Cognitive activity after SRC

The best evidence suggests that high cognitive activity early after SRC may exacerbate symptoms and delay recovery. The best evidence supports that reducing usual screen use in the first 48 hours after injury appears to facilitate SRC recovery but that screen time restriction beyond 48 hours is likely unnecessary.

An *acceptable-quality* prospective cohort study[51] found that participants who reported being in the highest quartile of cognitive activity-days within 3 weeks of SRC (0=complete cognitive rest, 4=full return to preinjury cognitive activity) took significantly longer to recover than those in the first to third quartiles. Initial visit symptom burden and cognitive activity-days were independently associated with symptom duration. A secondary analysis of an RCT[52] that did not meet the inclusion criteria (%SRC not reported) is worth mentioning because it reported that an abrupt increase in mental activity (ie, returning to school and extracurricular activities) increased the risk of a symptom spike (relative risk=2.28, 95% CI 1.05–4.95), although most were transient and did not delay recovery.

A recent RCT[53] that examined screen time use in the immediate recovery phase after concussion merits reporting even though it did not fulfil the inclusion criteria (sample <50% SRC). Patients aged 12–25 years presenting to the ED within 24 hours of concussion were randomised to those permitted to engage in screen time versus asked to abstain from screen time for 48 hours after the ED visit. Screen time-permitted group took longer to recover than the abstinent group (median 8.0 (IQR: 3.0 to >10.0 days) vs 3.5 days (IQR: 2.0 to >10.0 days); p=0.03). Screen time-permitted group reported a median of 630 min (IQR: 415–995 min) screen time versus 130 min (IQR: 61–275 min) for abstinent group. A planned secondary analysis of a prospective cohort study from five Canadian EDs,[54] published after the most recent search for inclusion in this SR (%SRC not reported), followed 633 children and adolescents (aged 8–16) with concussion and 334 orthopaedic injured (OI) controls beginning 7–10 days after injury. Reports of both low and high screen time were associated with relatively more severe symptoms in the concussion compared with the OI group during

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the first 30 days after injury but not after 30 days. Other risk factors and health behaviours had stronger associations with symptom severity than screen time.

Sleep after SRC

The best evidence supports that sleep disturbance early after injury appears to impair recovery from SRC.

In an *acceptable-quality* retrospective cohort study,[55] adolescents who reported trouble falling asleep or sleeping more or less than normal after SRC experienced more symptoms than those who denied sleep problems (p<0.001). An *acceptable-quality* retrospective study[56] of children found that those with initial sleep problems within 14 days of SRC took longer to recover than those without sleep problems (21 (10–27) vs 14 days (10–20); p=0.03). An *acceptable-quality* prospective cohort study[57] found that time in bed decreased throughout recovery after SRC (p=0.026) and that accelerometer metrics of poor sleep up to 6 days after injury were associated with worse reaction time at visit 2 (p<0.05). An *acceptable-quality* prospective cohort study[58] of college-age students showed that those with worse sleep quality after SRC took longer to recover than those with good sleep quality, and postinjury global sleep quality scores correlated with days to symptom recovery (p=0.007). An *acceptable-quality* prospective cohort study[59] within 72 hours of SRC measured total sleep time (TST, time spent asleep) and sleep efficiency (ratio of TST to total time between in-bed and out-of-bed times, reported as a percentage, SE%) during the 2 weeks following enrolment. Reduced TST and SE% were associated with more symptoms the next day, especially late in the day.

Meta-analyses and GRADE recommendations

The best evidence supports that early (within 2–14 days of injury) aerobic exercise treatment improves recovery after SRC by a mean of −4.64 days (95% CI −6.69, –2.59).

Seven studies were included in the meta-analysis on PA and exercise interventions (five RCTs, one prospective cohort and one retrospective cohort). One study compared an exercise intervention to both a rest control group and to a placebo stretching group, which produced eight comparisons (figure 4). Figure 4 shows that the pooled weighted mean difference was −4.64 days (95% CI −6.69, –2.59, I^2=50.9%; p=0.047). While the outcomes had moderate levels of heterogeneity, the precision of the top five studies was high; thus, variability was largely attributable to the underpowered studies (table 1). The GRADE recommendation for early prescribed exercise facilitating recovery was high because of the large number of RCTs included (table 1). PA received a moderate GRADE rating because most (93%) studies had a prospective/retrospective cohort design with less standardisation when compared with the prescribed exercise studies.

Meta-analyses could not be completed for rest (n=4), cognitive activity (n=7) and sleep (n=5) domains because heterogeneous methodologies and outcome measures limited the derivation of pooled estimates across studies. While subjective measures and/or unvalidated tools were used to assess cognitive activity, some homogeneity emerged in that days to recovery followed an upside-down parabolic trend, with too little or excessive cognitive activity delaying recovery. Sleep followed a similar trend, with poorer sleep quality/efficiency or longer time in bed delaying recovery. The GRADE quality ratings for cognitive activity and sleep domains were low while the rest domain, with two high-quality RCTs, received a moderate GRADE rating.

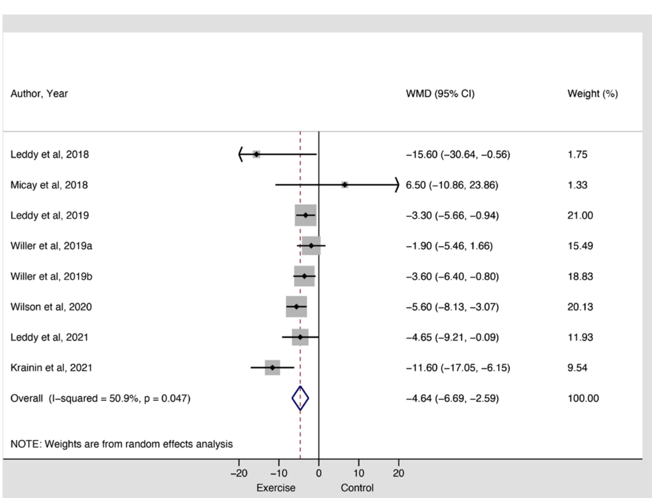

Figure 4 Forest plot depicting the impact of physical activity (PA) and prescribed exercise on recovery compared with a control group. Data from the Willer *et al*[48] article were included twice since it compared prescribed exercise to both a control rest group (2019a) and to a placebo stretching group (2019b). WMD, weighted mean difference.

DISCUSSION

This SR based its conclusions and recommendations on studies with the highest quality of evidence regarding the roles of PA, prescribed aerobic exercise, rest, cognitive activity and sleep for the early management of SRC.

General interpretation of results

In *symptomatic athletes*, the data support that spontaneous light PA (eg, activities of daily living (ADLs) and walking, which do not require assessment with formal exercise testing) facilitates recovery when started within 48 hours of SRC. Aerobic exercise *treatment* (based on systematic determination of the individual's level of exercise tolerance, ie, the HRt at the more-than-mild symptom exacerbation point on exercise testing) is safe and facilitates recovery when prescribed as soon as 2 days after SRC. Exercise testing should be performed only when the athlete reports the general resting concussion symptom burden is not >7/10 on a 0–10 visual analogue scale (VAS). The 0–10 VAS is used to estimate the severity of the combined concussion symptom burden at rest to help ensure safe exercise testing. This is opposed to the 0–6 scale used in the Sport Concussion Assessment Tool (SCAT) symptom inventory to gauge the severity of individual concussion symptoms early after injury. Early (within 2–14 days of injury) prescription of aerobic exercise treatment also significantly reduces the incidence of PPCS. This is important given that adolescents with PPCS suffer from reduced quality of life, psychosocial adjustment issues and learning difficulties in school.[60–62] The data suggest that adherence in the first week after evaluation is key, and that it is not only those who feel well enough to do aerobic exercise who benefit from it. Aerobic exercise treatment also facilitates recovery in athletes *with* PPCS. Aerobic exercise can safely be progressed systematically based on repeat exercise testing in a supervised environment (every few days to every week). Athletes without access to exercise testing can advance exercise according to the degree of symptom exacerbation experienced during the prior exercise bout. The data suggest that recommending strict rest from ADLs or from light PA at any time after SRC does not facilitate recovery, that reduced sleep quality early after SRC is associated with prolonged recovery, and that reducing usual screen use in the

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Table 1 GRADE assessment for studies examining the effect of physical activity, prescribed exercise, rest, cognitive activity and sleep on recovery after SRC

Quality assessment						Summary of findings		
Design	**Limitations (ROB)**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication bias**	**Pooled estimates (95% CI)**	**Quality rating**	**Comments**
Physical activity Prospective cohort (n=10) Retrospective cohort (n=4) RCT (n=1)	▶ Most studies relied on self-reported measures of exercise/physical activity rather than objective measures. ▶ Studies that assessed rest relied on self-report from participants. ▶ Limited reliable and valid objective cognitive exposure/outcome measures. ▶ Unvalidated sleep tools used and did not adjust for whether sleep problems were present before injury. ▶ Participants and researchers not blinded to interventions and most did not use intent-to-treat analyses. ▶ Studies primarily conducted in adolescents (13–17 years) and young adults (18–25 years) in North America. ▶ Minimal control for potential confounding variables. ▶ Potential for selection bias within the studies.	▶ Direction of effect showed strict rest or too much cognitive activity delayed recovery. ▶ Direction of the effect consistently showed exercise was beneficial; however, there was moderate heterogeneity due to smaller sample sizes in some studies. ▶ Direction of effect showed decreased sleep quality or efficiency prolonged recovery.	▶ Control group intervention varied: treatment as usual, rest or stretching exercise. ▶ Intensity, duration and modality of physical activity varied between studies and often relied on self-report. ▶ Aerobic exercise prescription (intervention) varied between studies. ▶ Possibility that control groups performed physical or cognitive activity that was not measured. ▶ Possibility that all participants could have received additional multifaceted treatment in addition to study interventions.	▶ Consistent trend in adequately powered trials for exercise reducing days to symptom resolution compared with control groups.	▶ Potential for studies promoting benefits of exercise, physical/ cognitive activity and/ or sleep treatment being published compared with those with null findings.	**Days to symptom resolution for prescribed exercise and physical activity compared with controls:** −4.64 days (−6.69, −2.59)	**Physical activity:** moderate	▶ Accounting for sample size, prescribed exercise treatment following concussion consistently reduced number of days to symptom resolution. ▶ The findings should be interpreted with the caveat that there was some degree of heterogeneity within the prescribed exercise intervention and control groups. Measurement error was possible in those studies where participants self-reported adherence to the exercise prescription. ▶ Complete rest was not beneficial for recovery. ▶ Too much or too little physical activity was associated with longer time to symptom resolution. ▶ Greater standardisation across studies examining cognitive activity and/ or sleep metrics acutely following concussion is warranted.
Prescribed exercise RCT (n=10) Retrospective cohort (n=4) Quasiexperimental (n=4) Prospective cohort (n=2) Pre-experimental (n=1)							**Exercise:** high	
Rest RCT (n=2) Prospective cohort (n=2) Retrospective cohort (n=1)						**Rest:** N/A	**Rest:** moderate	
Cognitive activity Prospective cohort (n=4) Retrospective cohort (n=2) RCT (n=1) Quasiexperimental (n=1)						**Cognitive activity:** N/A	**Cognitive activity:** low	
Sleep Prospective cohort (n=5) Retrospective cohort (n=4)						**Sleep:** N/A	**Sleep:** low	

GRADE, Grading of Recommendations, Assessment, Development and Evaluations; RCT, randomised controlled trial; ROB, risk of bias; SRC, sport-related concussion.

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first 48 hours after injury appears to facilitate recovery but that screen time restriction beyond 48 hours is likely unnecessary.

Paediatric-specific considerations

The fifth CISG statement included children (5–12 years) and adolescents (13–18 years) in the paediatric age group. Most papers included the paediatric age group, and while some included children ≤12 years, the majority assessed adolescents and young adults. Despite current evidence being predominantly applicable to adolescents, there is insufficient evidence to recommend strict rest until symptom resolution for children; to the contrary, it may delay recovery. As such, early PA and subsymptom threshold aerobic exercise in children should align with the paradigm in adolescents until age-specific data become available.

Implications for clinical practice and future research

The highest quality evidence in this SR shows that recommending strict rest until complete symptom resolution is not beneficial for SRC. Clinicians should recommend an early return to light PA (eg, ADLs and walking during the initial 48 hours after injury while avoiding risk of contact, collision or fall) that does not more than mildly exacerbate symptoms (defined as a >2 point increase and/or appearance of new symptoms when compared with the preactivity value on a 0–10 scale). Limiting cognitive activity for screen use during the first 48 hours appears to be warranted but there is no evidence that screen use after the first 48 hours delays recovery. Clinicians with access to exercise testing can prescribe targeted HR aerobic exercise treatment based on 90% of the individual's HRt at the more-than-mild symptom exacerbation point. The data show that it is safe to assess exercise tolerance and to prescribe 'mild symptom exacerbation' aerobic exercise treatment as early as 2 days after SRC, and that it reduces the risk of PPCS. In highly supervised and controlled settings (eg, college and professional), elite adult athletes with relatively low resting symptoms may, after medical assessment, undergo exercise testing within 24 hours of injury and perform aerobic exercise earlier than 2 days, but this approach requires further investigation. Symptom exacerbation during PA, prescribed aerobic exercise and cognitive activity is typically brief (ie, less than an hour) and does not delay recovery. Activity that more than mildly exacerbates symptoms, however, should be stopped until a return to the prior level of symptoms. Sleep disturbance after concussion might prolong recovery but further prospective research that controls for propensity to experience sleep disturbance is needed. The lack of a validated biomarker to monitor SRC recovery requires symptom recovery as the primary outcome measure. Future studies should examine the role of biomarkers to guide rest and exercise following SRC.

Key recommendations

- ⇒ Meta-analysis reveals that subsymptom threshold aerobic exercise treatment (based on formal exercise testing) should be prescribed to adolescents as soon as 2 days after sport-related concussion (SRC), which facilitates recovery by a mean of −4.64 days (95% CI −6.69, −2.59). Grading of Recommendations, Assessment, Development and Evaluations recommendation is high.
- ⇒ Subsymptom threshold aerobic exercise treatment (based on formal exercise testing) should be prescribed to adolescents as soon as 2 days after SRC to significantly reduce their incidence of persisting postconcussive symptoms (PPCS) beyond 1 month. Aerobic exercise is also effective for reducing symptoms in athletes who suffer from PPCS.
- ⇒ Adolescents and young adults should return to light physical activity (eg, walking and easy activities of daily living) and limit their cognitive activity and screen use within the first 48 hours after injury to facilitate recovery.
- ⇒ Concussion symptom exacerbation is typically brief, does not delay recovery and should not prevent athletes with SRC from resuming activity/exercise after brief relative rest.

Limitations

At the study level, only 7/46 (15%) articles were classified as 'high quality'; those that informed the guidelines were at least 'acceptable'. The most common reasons for reduced quality were weaker designs (eg, potential for recall bias due to retrospective nature, selection bias and lack of control for relevant known and unknown confounders), small sample size and a lower number of participants with SRC. Many studies used complete symptom resolution or return to preinjury life symptom level as the sole recovery criterion, which is problematic because of the non-specificity of concussion symptoms.[63]

At the review level, publication bias may have occurred as manuscripts promoting expedited recovery from concussion are more likely to be published. Nevertheless, we included high-quality RCTs and cohort studies that compared exercise treatment to resting control groups and to stretching placebo groups that consistently found greater early PA and prescribed exercise facilitated recovery. Finally, the included studies were all based within North America (USA and Canada) and primarily included adolescents or young adult collegiate athletes. Further research across various countries, ethnicities, ages and cultures is needed.

CONCLUSION

Evidence-based SRC management strategies during the 14 days after SRC include: (1) relative (not strict) rest during the first 48 hours after SRC, including introduction of ADLs, light PA and advice to reduce screen time; and (2) aerobic exercise treatment (based on formal exercise testing) prescribed as soon as 2 days after SRC in adolescents, which also reduces their risk of PPCS. Provided that athletes are instructed not to exceed their mild concussion symptom exacerbation thresholds, PA, cognitive activity and prescribed exercise are safe. Concussion symptom exacerbation is typically brief, does not delay recovery and should not prevent resumption of activity/exercise after brief relative rest. PA and prescribed aerobic exercise can be progressed systematically according to the degree of symptom exacerbation experienced during serial bouts of activity/exercise or, resources permitting, on repeat exercise testing. The evidence is strongest for adolescents and younger adults but may reasonably be extrapolated to children. Importantly, individuals should be advised to avoid risk of repeat head injury until they have recovered to the point where they are determined to be medically ready to return to activities at risk of contact, collision or fall.[64]

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