

AEROBIC TOLERANCE AND MOVEMENT-PROVOKED SYMPTOMS AFTER SPORT-RELATED CONCUSSION: A CRITICAL REVIEW OF ASSESSMENT AND REHABILITATION ENDPOINTS

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ABSTRACT

To examine the clinical significance of tolerated aerobic exercise when head movement or visual activity continues to provoke symptoms after sport-related concussion, and to distinguish rehabilitation improvement from readiness for sport. In a 2019 adolescent trial, median recovery was 13 days with aerobic exercise and 17 days with stretching. A 2014 cervicovestibular trial favoured clearance by eight weeks, whereas a 2022 adult trial found physical cervical and vestibular improvement without superiority in overall symptoms or return to function. These differences reflect distinct populations, comparators, and endpoints. Tolerance of low-intensity activity does not establish normal exertional capacity, and a positive head-motion screening item does not isolate an anatomical cause. Interpretation requires an adequately demanding graded exercise assessment, a specified movement task, and documentation of symptoms before, during, and after each activity. Additional rehabilitation should address an identified impairment and its functional restriction. The available trials do not directly establish the optimal treatment for athletes with normal aerobic tolerance and persistent movement-provoked symptoms. Clinical improvement must be assessed against the demands and risk of the next participation stage.

Keywords: sport-related concussion; exercise tolerance; head-motion symptoms; vestibulo-ocular assessment; cervicovestibular rehabilitation; return to sport.

INTRODUCTION

Stationary cycling, head turns during running, and ball tracking place different demands on an athlete recovering from concussion. Cycling may be tolerated while a movement task provokes dizziness or headache. Interpretation depends on the exercise intensity reached, the sensory and mechanical demands of the second task, and the interval between activities. The Amsterdam concussion recommendations require multimodal assessment and distinguish therapeutic activity from sport stages involving head-impact risk (Patricios et al., 2023).

Ellis and colleagues differentiated exercise intolerance, vestibulo-ocular dysfunction, and cervical dysfunction in 2015 and described individualized assessment and rehabilitation in 2018 (Ellis et al., 2015, 2018). Their approaches combine clinical examination with graded exercise testing and preservation of physical fitness during recovery. Symptoms alone cannot reliably distinguish these presentations (Leddy et al., 2015). A difference between exercise and head-motion responses therefore requires examination rather than assignment to a symptom-defined diagnosis.

The clinical question is what a successful task establishes. Completion of a cycling session documents tolerance at the dose performed. A graded exercise assessment evaluates exertional capacity under a defined protocol. A vestibular or cervical examination evaluates different functions, and medical clearance addresses participation requirements and injury risk. Each observation must retain its clinical meaning when rehabilitation decisions are made.

This review examines exercise and movement assessment, compares the outcomes of aerobic and targeted physical rehabilitation, and evaluates their relevance to return-to-sport decisions. Adolescents and young adults with sport-related concussion constitute the principal clinical population. Adult mild traumatic brain injury trials are considered separately because injury context, comparator treatment, and functional endpoints differ.

METHODS

SEARCH AND ELIGIBILITY

Europe PMC searches were restricted to PubMed records using SRC:MED. The four title-and-abstract searches returned 183 records for aerobic or graded exercise, 511 for cervical or vestibular terms, 83 for movement-related provocation, and 211 for return to sport or medical clearance. There were 839 distinct records across the searches. .

Relevant titles were examined, followed by abstracts of selected articles. Human investigations were eligible when they addressed exercise tolerance, head-motion or visual symptoms, cervical or vestibular assessment, or rehabilitation outcomes relevant to participation. Seven randomized comparisons were selected to represent early and persistent presentations, aerobic and targeted physical interventions, and stretching, usual-care, or active-aerobic comparators. This was a purposive narrative selection, not an exhaustive screening of every eligible trial. The 2023 systematic reviews provided the wider treatment context (Leddy et al., 2023; Schneider et al., 2023).

Trials involving moderate or severe traumatic brain injury, training in healthy participants, and protocols without treatment outcomes were excluded from effectiveness comparisons. Citation-directed retrieval was used for assessment investigations, international recommendations, and the physiological approaches to concussion management. Adult nonsport mild traumatic brain injury findings were used to examine the applicability of treatment effects across populations.

VERIFICATION AND APPRAISAL

For each rehabilitation trial, verification covered participant age, time since injury, allocation and analysis denominators, intervention dose, comparator content, endpoint, follow-up interval, and statistical uncertainty. DOI and PubMed identifiers were checked against bibliographic records. Numerical findings were checked against primary abstracts and publisher records. The full articles by Leddy et al. (2019) and Schneider et al. (2014) were examined for eligibility, blinding, withdrawals, and analysis. Full text was also available for the initial VOMS investigation, the peripheral-vertigo cohort, collaborative care, recovery predictors, and the 2018 physiological approach. Appraisal of the remaining treatment articles was limited to their abstracts and accessible publisher information.

Assessment considered selection, treatment comparison, outcome definition, blinding where documented, withdrawal handling, and estimate precision. Information absent from an abstract was treated as unavailable. Selection and verification were not independently duplicated, the review was not prospectively registered, and formal risk-of-bias scores were not assigned. Treatment outcomes were neither pooled nor ranked across incompatible endpoints. These procedures allow clinical comparison of the selected investigations but do not support a comprehensive estimate of effectiveness or prevalence.

CLINICAL DEFINITIONS

Tolerated activity denotes completion of a specified session with a documented symptom response. *Preserved aerobic tolerance* requires a supervised graded exercise assessment that meets the adopted protocol's criterion for a normal response. The record must identify intensity, symptoms, and the reason for stopping. Failure to reach the criterion leaves the result indeterminate. Early termination for leg fatigue, musculoskeletal pain, anxiety, or another limitation cannot establish normal concussion-related exercise tolerance.

Movement-provoked symptoms denote symptoms associated with a specified head-motion, gaze, visual-motion, or locomotor task. Documentation includes pretask symptoms, task duration and intensity, peak change, and settling time. *Aerobic-movement discordance* describes a normal response to an adequate aerobic assessment together with symptoms that recur during a separately interpretable movement task. Symptoms persisting from preceding activity or inadequate exertional intensity prevent confident classification. These descriptive terms have no validated diagnostic or clearance thresholds.

MEASUREMENT OF AEROBIC AND MOVEMENT TOLERANCE

GRADED EXERCISE AND TERMINATION CRITERIA

The graded-exercise reliability investigation found agreement in identifying symptom-exacerbation heart rate; part of the interrater assessment used actors (Leddy et al., 2011). Agreement between assessors does not establish the sensitivity of a normal test for cervical, ocular, or vestibular impairment. In 20 adolescents with concussion and 20 controls, Buffalo treadmill and bike tests produced similar symptom-exacerbation heart rates but different test durations (Haider et al., 2019). The modalities consequently cannot be assumed to impose identical balance, head-stabilization, or locomotor demands.

The assessment record should specify the protocol, modality, achieved workload, heart rate, perceived exertion, symptom change, and termination criterion. Heart rate at cessation is a symptom threshold only when symptom aggravation caused the test to end. An incomplete challenge can conceal exertional intolerance, while pain or another nonconcussion limitation can reduce the achieved workload for a different reason. Symptoms after exercise also require documentation.

Exertional dose must be considered when comparing cycling with a movement task. Running with head turns can add gaze stabilization and locomotor coordination while increasing cardiovascular demand. A symptom increase during running therefore cannot be assigned to head movement without considering intensity, duration, and preceding activity. The task response directs examination; it does not localize pathology.

OCULAR MOTOR AND HEAD-MOTION SCREENING

The Vestibular/Ocular Motor Screening assessment (VOMS) examines symptom responses to ocular motor, convergence, vestibulo-ocular, and visual-motion tasks. The initial investigation included 64 patients and 78 controls, and collegiate research further examined discrimination between concussion and control groups (Mucha et al., 2014; Kontos et al., 2021). Symptom change during a vestibulo-ocular reflex item is distinct from an objective measurement of reflex gain. A positive item does not isolate a central, peripheral, or cervical cause.

Head-motion discomfort may accompany vestibular or cervical impairment, migraine-related sensitivity, anxiety, or cumulative symptom aggravation. The examiner should identify the provoking task and document symptoms immediately before it. If exertion testing precedes head-motion screening, the task order, recovery interval, and persistence of earlier symptoms must be recorded. Recurrence during a comparable task supports interpretation, but no validated repeat-assessment criterion is established for the discordant pattern considered here.

CERVICAL AND PERIPHERAL VESTIBULAR FINDINGS

An interview study of 86 adolescent athletes described dizziness triggers and descriptors without establishing anatomical causes (Reneker et al., 2015). Neck pain and restricted movement warrant cervical examination, but their presence does not exclude vestibular dysfunction. Head rotation involves cervical, visual, and vestibular processes, so its symptom response cannot isolate the cervical contribution.

Among 102 children and adolescents referred for prolonged postconcussion dizziness, 30 had benign paroxysmal positional vertigo; assessment occurred a mean of 18.8 weeks after injury (Wang et al., 2021). The 29.4% proportion applies to that symptomatic referral cohort. It demonstrates the relevance of peripheral vestibular assessment without estimating incidence among all athletes with acute concussion. Examination for structural cervical injury and other contraindications precedes provocative cervical, vestibular, or positional testing where indicated (Ellis et al., 2018).

The assessment review accompanying SCOAT6 addresses neurological, cervical, vestibular, cognitive, and psychosocial evaluation (Patricios et al., 2023). These domains are relevant when exercise and movement responses differ. A tolerated aerobic task and a symptom-provocation score each supply part of the clinical examination.

REHABILITATION OUTCOMES

AEROBIC EXERCISE

In Leddy et al.'s 2019 trial, athletes aged 13–18 years presented within 10 days of concussion (Leddy et al., 2019). Of 113 randomized participants, 103 remained in the per-protocol analysis. Aerobic activity and stretching were prescribed for approximately 20 minutes daily; the aerobic target was 80% of symptom-exacerbation heart rate. Median recovery was 13 days (IQR 10–18.5) with aerobic exercise and 17 days (IQR 13–23) with stretching. Recovery required symptom

improvement, a blinded physician assessment, and normal treadmill tolerance. Athletes who could already exercise without symptom aggravation were excluded, limiting applicability to those with preserved aerobic tolerance; exclusions after randomization also qualify the estimate.

The 2021 multicentre trial included 118 adolescents and monitored exercise intensity and adherence (Leddy et al., 2021). The adjusted recovery hazard ratio for stretching relative to aerobic exercise was 0.52 (95% CI 0.28–0.97). The outcome was recovery, so the estimate describes the recovery hazard rather than a risk ratio for persistent symptoms. Neither trial assessed an additional treatment specifically after aerobic tolerance had normalized.

Kurowski et al. enrolled 30 adolescents with mild traumatic brain injury and symptoms lasting 4–16 weeks (Kurowski et al., 2017). Adolescent-rated Post-Concussion Symptom Inventory scores improved more rapidly with aerobic training than with stretching. The exploratory trial enrolled 22% of eligible patients; mean home-exercise frequency was 4.42 sessions/week with aerobic training and 5.85 with stretching. Its endpoint was symptom improvement rather than sport clearance. The 2023 exercise review supports early prescribed aerobic activity and distinguishes its benefits from prolonged strict rest (Leddy et al., 2023).

CERVICAL AND VESTIBULAR REHABILITATION

Schneider et al. allocated 31 participants aged 12–30 years to combined cervical and vestibular treatment or comparison care (Schneider et al., 2014). Both groups attended weekly sessions for up to eight weeks. Comparison care included education, range-of-motion exercise, rest until asymptomatic, and graded exertion. Two controls withdrew. Clearance occurred in 11/15 treated participants and 1/14 remaining controls. Classifying both withdrawals as cleared yielded an eight-week clearance risk ratio of 3.91 (95% CI 1.34–11.34). The interval is wide, and combined treatment prevents separation of cervical and vestibular effects.

Langevin et al. randomized 60 adults with persistent mild traumatic brain injury symptoms to six weeks of aerobic exercise with or without cervicovestibular rehabilitation (Langevin et al., 2022). Assessments occurred at weeks 6, 12, and 26. Additional rehabilitation improved vestibulo-ocular reflex and craniovertebral mobility findings at weeks 6 and 12, without superiority on the primary Post-Concussion Symptoms Scale or return to function. Nonsignificant group-by-time comparisons do not establish equivalence. The active-aerobic comparator and adult functional endpoint differ from the 2014 youth trial's comparison care and sport-clearance endpoint.

Clinical interpretation therefore depends on the additional benefit sought. Improved cervical movement or vestibular performance may support reassessment of the corresponding activity restriction. Faster unrestricted participation requires a participation endpoint and cannot be established from a physical measure alone.

VESTIBULAR EXERCISE AND EARLY PHYSICAL THERAPY

Kontos et al. enrolled 55 adolescents with vestibular symptoms or impairments within 21 days of concussion, and 50 completed the protocol (Kontos et al., 2021). Four weeks of vestibular exercise produced greater improvement in horizontal and vertical VOMS items than behavioural management; the visual-motion sensitivity interval included zero. Comparison care included activity and health-behaviour advice. The outcomes concern task-related symptoms rather than objective vestibular physiology or unrestricted sport readiness.

Reneker et al. randomized 41 participants aged 10–23 years with acute concussion and dizziness (Reneker et al., 2017). Physical therapy began at approximately day 10, comparing progressive individualized treatment with sham to minimally progressive intervention. Median time to medical clearance was 15.5 days with progressive treatment and 26 days with comparison care.

CLINICAL ASSESSMENT AND RETURN TO SPORT

EXERCISE INTENSITY AND SYMPTOM RESPONSE

A comfortable cycling session should be documented at its actual duration and intensity. If the adopted graded-test criterion has not been met, the record should not classify exertional capacity as normal. When adequate exertion is tolerated, head-motion or visual symptoms require assessment of the activity that remains limited, including its exertional component and the symptom level at task onset.

A trial in patients aged 11–22 years found no added benefit from five days of strict rest compared with usual shorter rest, with higher symptom ratings in the strict-rest group (Thomas et al., 2015). The Amsterdam recommendations permit mild, brief aggravation during appropriate early activity: no more than a two-point increase on a 0–10 symptom scale for less

than one hour (Patricios et al., 2023). This activity-dosing convention is separate from graded-test termination criteria and requirements for head-impact exposure.

Table 1 distinguishes inadequate exertional assessment, movement symptoms following adequate assessment, cumulative provocation, and difficulty during sport activity. The assessment patterns require qualified clinical supervision after concussion diagnosis and evaluation of relevant contraindications.

TABLE 1. EXERCISE AND MOVEMENT OBSERVATIONS THAT REQUIRE REASSESSMENT BEFORE SPORT PROGRESSION.

Observation	Assessment requirement	Management implication
An exercise session is tolerated, but intensity is low or termination reflects another limitation.	Specify the graded protocol, achieved workload, symptom change, perceived exertion, and reason for stopping.	Retain the description "tolerated activity." An incomplete challenge cannot establish normal exercise tolerance (Leddy et al., 2011; Haider et al., 2019).
Adequate aerobic assessment is tolerated; symptoms recur during a separate movement task.	Identify the provoking head, gaze, positional, visual, or locomotor demand and examine cervical, vestibular, ocular, and migraine-related findings.	Continue medically appropriate tolerated activity. Select additional treatment for the identified impairment (Ellis et al., 2018; Mucha et al., 2014; Wang et al., 2021; Patricios et al., 2023).
Symptoms occur across assessments, or increase during later tasks before prior symptoms have settled.	Determine whether the task began before symptoms from preceding activity had settled, and whether exertional intensity changed.	Record task order, intervals, and pretask symptoms. Repeat assessment when the contribution of the preceding activity cannot be separated.
Clinical tasks are tolerated, but sport-specific activity remains difficult.	Assess direction changes, visual tracking, exertional duration, cognitive demands, confidence, and concurrent injury relevant to the sport.	Use medically supervised staged sport exposure and reassessment. Authorization for head-impact risk requires a separate clinical decision (Patricios et al., 2023,?).

RECOVERY STAGE AND TREATMENT SELECTION

Days since injury and symptom trajectory must accompany the task findings. Early adolescent exercise trials, a trial with symptoms lasting 4–16 weeks, and adult persistent-symptom rehabilitation address different stages of recovery. Their findings cannot be transferred without considering age, injury context, symptom duration, and existing treatment. Applicability to younger children, older adults, and athletes with important comorbidities remains uncertain.

Treatment selection should connect an examination finding to an activity restriction. Positional vertigo, painful restricted cervical movement, gaze instability, visual-motion symptoms, and exertional aggravation require different assessments. An uncertain finding warrants reassessment or specialist evaluation. The available evidence does not justify identical vestibular exercises or combined treatment for every athlete with head-motion symptoms.

The relevant activity should be assessed after treatment. Reduced symptoms during a VOMS item support evaluation of gaze-task tolerance; improved cervical mobility supports evaluation of head movement. Sport exposure may additionally require repeated accelerations, direction changes, ball tracking, decisions during movement, and sustained training duration. These demands must be selected for the athlete's sport and medical restrictions.

PARTICIPATION CRITERIA

Targeted physical change, overall symptom burden, tolerance of sport activity, and authorization for participation are distinct endpoints. Improvement supports the next assessment when it addresses the restriction relevant to that participation stage. It does not automatically satisfy the demands of the next stage.

Before activity carrying head-impact risk, the Amsterdam recommendations require resolution of concussion-related symptoms and relevant cognitive or clinical abnormalities, including during and after exertion (Patricios et al., 2023). Prescribing therapeutic activity within appropriate symptom limits and authorizing head-impact exposure consequently require separate decisions. The assessment patterns in Table 1 do not replace those requirements.

In a randomized trial of 200 adolescents with persistent symptoms, collaborative care improved adolescent-rated symptoms and quality of life compared with usual care (McCarty et al., 2021). Sleep, distress, school demands, and continuing psychosocial difficulties may influence participation alongside physical impairments. Assessment should address these restrictions when physical treatment alone has not restored function.

APPLICABILITY AND LIMITATIONS

The rehabilitation trials did not enroll participants specifically because they had normal aerobic tolerance with persistent movement-provoked symptoms. Their results therefore do not establish the prevalence, prognosis, or additional treatment

benefit for that pattern. The seven comparisons demonstrate the importance of participant selection, comparator care, and endpoint definition; they do not establish a treatment sequence for the discordant response.

Purposive selection, English-language emphasis, variable full-text access, and absence of independent duplicate verification limit completeness. Recovery definitions and comparator content differ across trials. Combined interventions cannot identify the effect of each component, and an inconclusive comparison does not prove equivalence. Adverse events were not comprehensively tabulated, so the review does not establish safety across all ages, doses, or clinical presentations.

Clinical evaluation of this pattern requires a named aerobic protocol, its normal-response criterion, a specified movement task, and symptom measurements before and after each activity. Treatment comparisons would need to measure the additional benefit over suitable active care using the endpoint under investigation: movement tolerance, functional participation, or time to sport clearance. Initial symptom burden also requires consideration because it consistently relates to slower recovery (Iverson et al., 2017). The existing comparisons do not provide a defensible treatment-effect estimate or sample-size assumption for athletes selected on the basis of the discordant pattern.

Clinical task tolerance does not establish normalization of every biological process. Physiological recovery research has not identified a universal recovery interval or routine biomarker threshold for clearance (Kamins et al., 2017). Decisions should therefore remain tied to the clinical assessment and participation requirements rather than indefinite restriction based on an unvalidated biological criterion.

CONCLUSION

Aerobic tolerance and persistent head-motion symptoms can coexist after sport-related concussion. Interpretation requires completion of an adequate graded assessment and documentation of a separate movement task with its pretask symptoms, dose, and recovery interval. Aerobic and targeted rehabilitation trials support specific treatment effects within their studied populations, but none directly establishes optimal additional treatment after aerobic tolerance has normalized. Clinicians should assess the remaining impairment, reassess the corresponding activity restriction, and apply the requirements of the next sport stage before authorizing participation.

DECLARATIONS

AUTHOR CONTRIBUTIONS

All authors contributed equally and all authors read and approved the final version of this manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this study.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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