Articles	**Abbreviations:**

ACSM = American College of Sports Medicine
ADHD = attention deficit hyperactivity disorder
AMMP = Assessment of Military Multitasking Performance
ANAM4 TME = Automated Neuropsychological Assessment Metrics TBI Mil-Expanded Battery
ANS = autonomic nervous system
AUC = area under the curve
BESS = Balance Error Scoring System
BCTT = Buffalo Concussion Treadmill Test
BP = blood pressure
CES = combat exposure scale
cNP testing = computerized neuropsychological testing
CVLT II = California verbal learning test-second edition
d/t = due to
DVBIC = Defense and Veterans Brain Injury Center
ECG = electrocardiogram
ED = emergency department
FC = face cooling test
GCS = Glasgow Coma Scale
GGT = Gapski-Goodman Test
GXT = graded exercise test
HA = headache
HC = healthy control
HR = heart rate
HRt = heart rate threshold
hx = history
IED = improvised explosive device
ImPACT=Immediate Post Concussion Assessment & Cognitive Testing
LOC = loss of consciousness
MEB-disabled = medically retired-disabled
mo = month
MIDN = U.S. Navy Midshipmen
mTBI = mild traumatic brain injury
M-BESS = Modified Balance Error Scoring System
NPV = negative predictive value
NSI = Neurobehavioral symptom inventory
OP = outpatient
PCM = primary care manager
PCS = post-concussion syndrome
PCSS = post-concussion symptom scale
PEMT = Patrol-Exertion Multitask
PPCS = Persistent Post-Concussive Symptoms
PPV = positive predictive value
PRA-CR = Progressive Return to Activity Clinical Recommendation
RCI = reliable change index
RCT = randomized controlled trial
RMSSD = Root mean square of successive differences
ROC curve = receiver operating characteristics curve
RPE = rate of perceived exertion
RRI = R-R interval
RT = reaction time
RTA = return to activity
RTD = return to duty
RTL = return to learn
RTP = return to play
RTS = return to sport
SCAT-2 = Sport Concussion Assessment Tool, Version 2
SCAT 3 = Sport Concussion Assessment Tool, Version 3
SM(s) = servicemember(s)
SRC = sports related concussion
SRT = simple reaction time
sxs = symptoms
SSRC = Symptomatic sport related concussion
TBI = traumatic brain injury
V_E = minute ventilation
VAS = Visual Analog Scale
VOMS = Vestibular Ocular Motor Screening
VCO_2 = carbon dioxide production
VO_2 = oxygen consumption
WAIS-IV = Weschler adult intelligence scale-fourth edition
  WAIS-IV FSIQ = full scale IQ
  WAIS-IV WMI = working memory index
  WAIS-IV PSI = processing speed index
w/o = without
WRAT = Wide Range Achievement Test
WTAR = Wechsler test of adult reading
yo = years old
Δ = change

Study Details	Subjects/ Location	Inclusion/ Exclusion Criteria	Outcome Measures and Time Frame	Description of Intervention	Results	Conclusion
Authors: Leddy JJ, Haider MN, Ellis MJ, et al. **Title:** Early Subthres-hold Aerobic Exercise for Sport-Related Concussion : A Random-ized Clinical Trial. **Year:** 2019 **Country:** USA **Design:** RCT	103 participants; aerobic group (n=52) and stretching group (n=51) **Location:** 3 University-based outpatient concussion management clinics in western NY and 1 clinic in Winnipeg, Manitoba, Canada	**Inclusion:** Male and female athletes 13-18 years old; within 10 days of a SRC **Exclusion:** evidence of focal neurological deficit; inability to exercise d/t orthopedic injury; cervical spine injury; diabetes; known heart disease; increased cardiac risk according to ACSM criteria; hx of moderate or severe TBI; diagnosis of ADHD, learning disorder, depression, anxiety; 3+ concussions; sustaining another head injury; <5 on PCSS; inability to exercise to exhaustion without sxs exacerbation; limited English proficiency	**Measures:** Primary: days from injury to recovery. Recovery confirmed by: score ≤ 7 points on PCSS for 3 consecutive days, normal physical assessment by blinded physician, returning to normal tolerance on BCTT Secondary: proportion of participants with delayed recovery (>30 days and daily symptom scores) **Time Frame:** Following 1st visit participants were followed weekly by physician until recovery or for 30 days. If participant did not recover by 30 day mark they received treatment at the clinic. All participants were followed to determine days to recovery. Recruitment between September 2015 and June 2018.	All participants underwent a thorough history, standardized physical examination, and BCTT. Randomized to 1) aerobic exercise treatment OR 2) stretching exercise program (did not begin interventions until >48 hours after injury); both groups wore Polar H7 HR sensor and fitness tracker. Target HR and exercises updated weekly with BCTT. Symptoms and exercises reported daily for 30 days or until they had recovered. **Aerobic group:** exercised each day in the gym under supervision or at home at a prescribed target HR that was updated weekly (80% of HR achieved at sxs exacerbation on BCTT). Exercise session ended if sxs increased by 2(+) pts. **Stretching group:** followed stretching program while wearing HR monitor and received a progressive stretching program booklet.	No demographic or clinical differences between participants in two groups and no significant differences in previous concussions, time since injury, initial symptom score, initial BCTT, and physical examination. Few participants in both groups had brief LOC at time of injury. **Recovery time:** aerobic group recovered significantly faster than the stretching group (median of 13 days vs 17 days). Greater incidence of participants in stretching group had delayed recovery (median of 7 vs 2) but this was not significant. No significant difference between groups on daily symptom reporting compliance.	Based on the results of the multicenter RCT, early sub-symptom threshold aerobic exercise is a safe and appropriate intervention in adolescents within 1 week of injury. Compared to stretching, low intensity aerobic exercise prescribed at sub-symptom threshold may aid in preventing a delayed recovery time. Larger prospective studies with participant observation by researchers, and analysis of potential mechanisms associated with improved recovery with prescribed exercise early after injury should be performed in the future.
Authors: Leddy JJ, Hinds AL, Miecznikо	Male and female high school athletes referred to	**Inclusion**: male or female adolescent high school athletes (14-19 yo); sustained SRC and	**Measures**: -Days to recovery -Typical (≤ 21 days) vs prolonged recovery (>21 days)	Baseline: standard clinical evaluation (hx & physical examination) by research physician to confirm concussion. Randomized	No demographic or clinical differences between groups (age, sex, number of previous concussions, days since	Results of this RCT suggest the BCTT does not cause a short term acute increase in symptoms that would

wski J, et al. **Title:** Safety and Prognostic Utility of Provoca-tive Exercise Testing in Acutely Concussed Adolescent s **Year:** 2018 **Country:** USA **Design:** RCT	University at Buffalo Concussion Management Clinics & Excelsior Concussion Clinic (NY); data from 27 subjects in each group was analyzed **Location**: University and community sports medicine centers in NY	evaluated by a study physician within 1-10 days after injury **Exclusion**: evidence of focal neurological deficit; inability to exercise d/t orthopedic injury; cervical spine injury; diabetes or known heart disease; increased cardiac risk; current diagnosis of ADHD, learning disorder, depression, or anxiety; hx of moderate or severe TBI; 3(+) previous concussions; inability to speak English	Recovery defined as: normal symptom severity score on PCSS, exercise tolerance on BCTT, normal physical examination, and normal cognitive performance on ImPACT -HRt during the BCTT **Timeframe:** Assessments were performed at the 1st visit and 14 days after. Subjects were followed with biweekly visits until they met recovery criteria.	to BCTT or standard care/control group. All subjects performed the ImPACT on the 1st visit and the BCTT group also performed the treadmill test. Subjects in both groups reported symptoms on the PCSS on an online form between 1st and 2nd visit (14 days after initial visit). All participants performed the BCTT and ImPACT at visit #2 and subjects not recovered by then continued to be followed with biweekly visits until symptoms/ examination results normalized and exercise could be tolerated. See page 3 of article for BCTT protocol.	injury, or PCSS at visit 1). Days to recovery was not significantly associated with BCTT status, and group variable (BCTT/control) was not significantly associated with symptom score. In both groups PCSS significantly decreased over time. HRt was significantly associated with days to recovery (every 1 bpm increase in HRt resulted in 0.82 days shorter recovery phase) and with time to recovery in a model that included total symptom score. Symptom score alone was not significantly associated with days to recovery.	delay recovery. Structured exercise within a week after a SRC is safe in order to determine exercise tolerance. There is prognostic value in the degree of early exercise intolerance as determined by HRt value. The findings from this study indicate a lower HRt (from the last minute of the BCTT) could result in a longer recovery time and should be considered in addition to total symptom score. Subjects were not blinded and results cannot be generalized to other subgroups.
Authors: Scherer MR, Weightman MM, Radomski MV, et al. **Title:** Measuring Soldier Performanc e During the Patrol-Exertion Multitask: Preliminary	Healthy Controls (HC) (n=51) recruited at installation briefings / in response to recruitment flyers; participants with mTBI (n=33) recruited from clinical population receiving	**Inclusion HC:** SMs 18-42 yo; asymptomatic (if had remote hx of concussion); deployable; not currently receiving rehabilitation services **Inclusion mTBI:** SM recovering from mTBI sustained 2 weeks to 2 years before testing **Exclusion:** Duty status restricted with	**Measures:** PEMT: based on performance in 4 subtasks during a 12 min. patrolling scenario; primary metrics: 1) IED marker/patrol question responses 2) self-report visual clarity 3) self-reported RPE 4) instrumented RT responses **Time Frame:** 1 time testing session lasting up to 3 hours	All participants completed testing for the battery of the AMMP, including the PEMT, intake questionnaire, and series of neurocognitive tests. PEMT includes a 12-min. virtual reality scenario of a patrol in Afghanistan. Participants reported observed IED markers and continuously stepped on a 6 inch step during the scenario (maintained HR between 65-85% max). During the task an army	Significant between group differences for age, education, service time, deployment status, and WRAT score. Significant differences were found between HC and mTBI cohorts for visual clarity during baseline (P=0.002) and late stepping (P<0.001). Groups were significantly different in terms of RT responses in early (P=0.013) and late PEMT (P=0.002) protocol. mTBI group	Results from this study support the use of "ecologically valid testing" to challenge various mTBI-susceptible domains, such as cognition, exertional tolerance, and gaze stability during exertion to identify symptoms of post-concussive exercise intolerance. Significant between-group differences on self-reported visual

Validation of a Post-concussive Functional Return-to-Duty Metric. **Year:** 2018 **Country:** USA **Design:** Measure-ment develop-ment study	outpatient rehabilitation services at Womack Army Medical Center TBI Clinic **Location:** non-clinical testing facility at Fort Bragg, NC	a military medical profile (prevented continuous activity +30 min); history of a psychiatric disorder; moderate/ severe/penetrating TBI; uncorrected hearing or visual deficits prevented functional hearing /vision; HC excluded if reported a concussion within 12 mo preceding		combat helmet, clear eye protection, and Polar FT1 chest mounted HR monitor were worn. SMs carried a simulated M-4 weapon and were instructed to grip trigger immediately after hearing audio cue. SMs reported RPE and visual clarity several times during scenario, and were asked post-patrol questions. SRT tested before and after 6 task AMMP battery.	demonstrated increased response latencies. Significant but low correlation found between pre-battery SRT and RT during PEMT ($P=0.018$, $r=0.26$), and moderate correlation between post-battery SRT and RT during PEMT. ($P<0.001$, $r=0.45$)	clarity indicates the benefit of utilizing a functional RTD metric. The scenario-based RT while managing cognitive and physical loads were sensitive to the group, highlighting the importance of utilizing multimodal assessment strategies. *Limitation:* bias d/t between group differences
Authors: Quatman-Yates C, Bailes A, Constand S, et al. **Title:** Exertional Tolerance Assessments After Mild Traumatic Brain Injury: A Systematic Review **Year:** 2017 **Country:** USA **Design:** Systematic Review	Search was performed using PubMed and an EBSCOhost package. Subjects in the various studies were young athletes (elementary, high school, or college age); 2685 articles identified. **Location**: Ohio	**Inclusion criteria for selected studies:** 1) inclusion of participants with mTBI/concussion 2) use of a measurement of physiological or psychometric response to exertion 3) repeatable description of the exertion protocol provided 4) sample of ≥10 participants w mean age 8-65 yo 5) article in English **Exclusion Criteria:** case studies, non-empirical research articles, review articles, animal tests, and experiments done only in	**Measures:** A unique quality appraisal checklist was created for this study based off the Cochrane Risk of Bias Tool, Joanna Briggs Institute Clinical Appraisal Tools Checklist for Cohort Studies to assess for bias and relevance to study's purpose. Highest score = 10 **Timeline:** Literature review was conducted on July 15, 2016 and search repeated on December 31, 2016 and July 20, 2017	2 independent reviewers performed literature search on 3 separate occasions. Data search terms related to concussion and exercise testing/assessment (see methods). Search process included gray literature. Screening for relevancy was completed by 2 independent researchers and a 3rd reviewer if there were any disagreements. Extracted characteristics: purpose, sample, exercise modality, protocol details, relevant outcome measures, results, and limitations. Quality assessment conducted for each study independently by 2 team members. Key themes relevant to current post-mTBI exertional testing clinical and	14 studies appropriate for review. In half the studies mean age >18 years. Studies varied in terms of samples of athletes, athletes and nonathletes, or unspecified. In 5 studies exertional assessments performed in acute phase (1-3wks post injury), in 7 participants were in subacute/chronic phase, 1 was a retrospective chart review, and others involved an initial test in acute phase and 2nd test when asymptomatic. 5 used BCTT, 7 used cycle ergometry/stationary biking as exertion test. All assessed and evaluated HR, 8 included a post-mTBI sxs checklist /assessment, 5 evaluated	The cumulative findings from this systematic review suggest that post-mTBI exertional testing can be safe and beneficial in identifying residual impairments. More specifically, exertional testing may reveal "impaired physiological responses to exertion" which may present as altered HR variability, blunted HR response, and/or symptom exacerbation. Across these studies sample characteristics and outcome measures varied. The optimal protocols, modes, and measures for

		moderate or severe TBI populations		research strategies/rationales identified.	BP, and 6 evaluated RPE. 12 used a prospective design and 8 examined body's response to exertion test. BCTT was only test with reliability relative to mTBI.	exertional testing post-mTBI are still unclear.
Authors: Haider MN, Leddy JJ, Pavlesen S, Kluczynski M, Baker JG, Mieczkiowski JC, Willer BS. **Title:** A systematic review of criteria used to define recovery from sport-related concussion in youth athletes **Year:** 2018 **Country:** USA **Design:** Systematic Review	Electronic databases searched: PubMed (MEDLINE), SPORTDiscus and Embase Search produced 2294 articles, full texts of 261 evaluated. **Location:** Buffalo, NY	**Inclusion:** elementary, high school and college age groups; a specific definition of clinical recovery that required 2(+) measures; published in English **Exclusion:** review articles; articles using the same population; case studies; non-English language and those that used 1 measure only or did not specify the recovery measure used. Also excluded articles that did not state athlete had recovered or was ready to return to sport/school and where a physician had not specified basis of clinical decision. Articles excluded if they did not include sufficient detail about RTS protocol.	**Measure:** Study quality was assessed using the Downs and Black Criteria **Timeframe:** Databases searched between 1 January 2000 and 1 March 2017 by 3 independent researchers.	Search terms in "literature search section" of review. 3 reviewers independently extracted the following variables: author, year, study design, sample size, patient age, time to recovery, and definition of recovery. Recovery measures in studies categorized as: symptoms, cognitive performance at rest, special physical examination, balance, sxs exacerbation during physical exertion, sxs exacerbation during cognitive exertion, ability to maintain academic performance, and special tests. Risk of bias assessed with Downs and Black Checklist and level of evidence determined with guidelines by Melnyk and Fine-out Overholt.	43 articles included in review. 38 were case-control/cohort studies. Most were low quality (level 4) and had significant risk of bias. All studies reported symptom recovery, 37 used neurocognitive testing, 21 used a provocative exercise test, and 5 used special physical exam. A majority of the studies used PCSS to report symptom recovery (31), but cut-off for minimal sxs score varied. ImPACT was most frequently used as a computerized cognitive test (27 studies). 17 studies used a non-specific definition of provocative exercise to test for sxs exacerbation and 3 used BCTT. Most common balance measure was the BESS (11 studies). Most common combined recovery criteria used were somatic sxs scales and cognitive	Findings from this study indicate varying criteria used in the literature for RTS (many articles did not define recovery with objective measures) and a minority of studies used multiple measures of recovery. Symptom and cognitive recovery are most commonly used to guide recovery from SRC, but usually the only outcome used is symptom resolution. Relying solely on symptom reports may be problematic as symptoms are often non-specific and "may not coincide with brain recovery" as physiologic abnormalities may persist. Futures studies should consider multimodal testing, which could offer a more comprehensive picture of the young athlete's cognitive and

					performance (11 articles). 8 studies followed up with subjects.	physiological recovery post SRC.
Authors: Bailie JM, Remigio-Baker RA, Cole WR, et al. **Title:** Use of the Progressive Return to Activity Guidelines May Expedite Symptom Resolution After Concussion for Active Duty Military **Year:** 2019 **Country:** USA **Design:** Cohort study	38 military medical providers and 106 military SMs with a diagnosed concussion (126 participants initially enrolled – 64 in usual treatment (UT) group and 54 in progressive return to activity (PRA) group); 33 in UT group and 19 in PRA group completed all data collection time points **Location**: primary care and concussion care facilities at 3 US military installations. Study conducted	**Inclusion:** SMs being treated by an enrolled PCM for a concussion sustained ≤ 72 hours; concussion diagnoses verified in electronic medical record based on Veterans Administration/DoD definition for mTBI/concussion **Exclusion**: Hx of moderate or severe TBI or TBI of any severity sustained in the preceding 12 mo.	**Measures:** Primary: Neurobehavioral Symptom Inventory: 22 symptoms rated; total score & 4 sub-scores examined (cognitive, vestibular, somatosensory, affective symptoms) Others: -Activity questionnaire: # of days participants engaged in the activity on Likert scale (compliance w PRA-CR) -demographic info collected and CES administered -Answered whether they received oral/written education about their concussion at initial medical encounter **Timeframe:** Data collected from patient participants at 5 assessments after injury: </= 72 hours, 1 week, 1 month, 3 months, and 6 months	Purpose: study and compare patterns of recovery between patients who received treatment either before (UT group) or after (PRA group) their PCM participated in an educational intervention on the DVBIC's Return to Activity Clinical Recommendation (PRA-CR) for acute concussion; Providers participated in a 2 hour face-to-face standardized interactive case-based training, and implementation of the PRA-CR in each provider's practice was directly assessed via pre- and post-intervention semi-structured interviews conducted by research staff.	No demographic differences between groups (age, sex, marital status, level of education, branch, etc.) and no difference in lifetime TBI history. UT group had a higher level of combat exposure. UT and PRA groups did not differ in total NSI scores or sub-scores at ≤ 72 hours post injury. SMs in PRA group were 59% more likely to receive written education than those in UT group treated before provider education. PRA group had a smaller mean +/-SD increase in vestibular/balance activities and physical activities between ≤ 72 hours and 1 week, and at 1 week the PRA group had significantly lower symptoms than UT group on NSI total and cognitive and affective sub-scores. At 1 month post injury PRA group had lower levels of self-reported sxs on all NSI sub-scores, at 3 months all sub-scores except vestibular were lower for the PRA group, and at 6	SMs that were treated for an acute concussion after their PCM had received PRA-CR training demonstrated greater symptom reduction at 1 week, 1 month, and 3 months post-injury than those treated by the providers before receiving training. The results suggest that patients treated by providers with this training more gradually increase their activity during the 1st week and up to 3 months post-injury. The findings from this study indicate the benefit in training military medical providers on PRA guidelines set forth by the DVBIC.

	between 2016-2018				months no difference was observed between groups on NSI scores.	
Authors: Haider MN, Leddy JJ, Wilber CG, Viera KB, Bezherano I, Wilkins KJ, Mieczniko wski JC, Willer BS **Title:** The Predictive Capacity of the Buffalo Concussion Treadmill Test After Sport-Related Concussion in Adolescent s **Year:** 2019 **Country of Study:** USA **Design:** Retrospecti ve Cohort Design	Data from 2 published RCTs used - 1st recruited between March 2013 - February 2015, and the 2nd between September 2015 and June 2018; Acutely concussed adolescent athletes - rest group (RG) n=27, placebo group (PG) n=51, and aerobic group (AG) n=52 **Location:** Athletes seen at the University Concussion Management Clinics (University at Buffalo)	**Inclusion**: male and female adolescent athletes 13-18 years old; diagnosed with a concussion within 10 days of sustaining a SRC **Exclusion:** evidence of focal neurological deficits; inability to safely walk on a treadmill due to orthopedic injury or significant vestibular dysfunction; increased cardiac risk according to ACSM criteria; hx of moderate or severe TBI (GCS≤12); current diagnosis of and treatment for ADHD, learning disorder, depression, anxiety; hx of 3(+) prior concussions; sustaining another head injury during the research period; symptom severity score <5 on initial visit questionnaire; limited English proficiency	**Measures:** Primary: Recovery - defined as symptom resolution to baseline (confirmed by physical examination) and ability to exercise to exhaustion without exacerbation of symptoms on the BCTT; Others: -ΔHR (difference between resting HR and HRt) on the BCTT - VAS - RPE **Time Frame:** Data from two published RCTs was used (one study recruited between March 2014 and February 2015, and the other recruited between September 2015 and June 2018). Participants underwent a baseline exam and were followed under they were cleared for play or for up to 4 weeks.	Acutely concussed adolescents divided into 3 groups: RG, PG, and AG. All performed the BCTT to assess for degree of exercise tolerance and reported sxs online daily (with PCSS) between a specified time window until cleared to return to play or up to 4 weeks. All participants seen weekly and were referred for cervical or vestibular therapy if they did not recover by 30 days post-injury. **RG**: prescribed cognitive and physical rest; same advice provided until clinical recovery **PG**: prescribed cognitive rest and light stretching and breathing exercises (new exercises provided each week); instructed to wear HR monitor while stretching and not participate in activities that could raise their HR or exacerbate their symptoms **AG**: instructed to perform aerobic exercise at 80% of HRt achieved on BCTT for 20 min/day (while wearing HR monitor). BCTT performed every week and new HR	No significant differences in initial visit BCTT results between the 3 groups. ΔHR was significantly correlated with duration of clinical recovery for the RG ($p=0.012$, $R^2=0.228$) and PG ($p=0.011$, $R^2=0.126$), but not AG ($p=0.084$, $R^2=0.059$). Mean ΔHR for patients that developed PPCS was significantly lower in RG and PG. ΔHR was not significantly associated with duration of clinical recovery in AG group. ROC curve for ΔHR and PPCS for rest group and placebo group combined indicated that ΔHR of ≤50bpm was 73% sensitive and 78% specific for identifying adolescents who experienced a delayed recovery.	In this study ΔHR was correlated with duration of clinical recovery in participants prescribed rest or a placebo stretch program. More specifically, a ΔHR ≤50bpm was 73% sensitive and 78% specific for identifying adolescents who experienced delayed relay. The findings of this study suggest the benefit in using ΔHR on an exercise test as an objective prognostic measure for recovery early after a concussion. ΔHR could be used as a "clinically reasonable physiological biomarker of concussion" and this study has implications for return-to-activity planning. Future research should control for factors which influence HR and supervision of prescribed exercise may promote better compliance and adherence.

				prescription was provided each week until recovery.		
Authors: Orr R, Bogg T, Fyffe A, Lam LT, Browne GJ **Title:** Graded Exercise Testing Predicts Recovery Trajectory of Concussion in Children and Adolescents **Year:** 2018 **Country of Study:** Australia **Design:** Prospective Cohort Study	Participants were 12-16 yo (total n=139, exercise tolerant n=76, exercise intolerant n=64) and referred from emergency departments, specialties/ general practitioner, & brain injury services. Concussions were associated with organized sport or recreational activities. **Location**: Children's Hospital Institute of Sports Medicine (CHISM), Children's Hospital, Westmead, Australia	**Inclusion:** aged 12-16 yo; referred to CHISM within 5-7 days after an acute sports- or recreation-related concussion (diagnosed according to International Consensus on Concussion in Sport) **Exclusion:** non-sport/recreation related concussion; those w/moderate or severe TBI; those with traumatic abnormalities detected on clinical neuroimaging studies	**Measure:** Primary: clinical recovery measured as: 1)expected vs prolonged recovery 2)time to RTA in days Recovery defined as: normalization of clinical score for PCSS, VOMS, M-BESS, and ImPACT, and dissipation of concussion sxs on symptom-limited GXT **Timeframe:** Conducted between October 2014 – February 2016	Participants performed a battery of clinical assessments at baseline & every 2 weeks for follow-up until cleared to RTS. Assessments included a medical hx interview, neurological exam, VOMS, M-BESS, ImPACT, and GXT. An adapted Bruce protocol (same grades and progressive speeds on treadmill) was used for the GXT (participants connected to a metabolic cart & wore a pulse oximeter). HR, RPE, and sxs severity score on the Wong-Baker Faces Pain Rating Scale recorded throughout the GXT. Subacute baseline assessment by GXT demarcated 2 groups: exercise tolerant (≥9 min on GXT) vs exercise intolerant (<9 min). RTA protocol determined by GXT and clinical testing, and subjects were reassessed every 2 weeks until clinical recovery, when a final assessment was performed.	n=139, mean age 12.4± 2.8 years, 73% men; 76% of referrals from ED, 65% of mTBIs occurred during organized sport and 35% during recreational activities; 40% experienced LOC and 35% retrograde amnesia; at baseline exercise tolerant group performed GXT 10.3±3.3 min w/o progression of sxs score and intolerant group performed it for 4.2 ±1.6 min before progression of sxs score. In both groups main sxs were headache and balance/vestibular dysfunction. Most significant predictors of prolonged recovery = exacerbation of HA, balance, &/or vestibular dysfunction by exercise (P<0.001). Exercise duration <9 min and positive M-BESS were significant predictors of prolonged recovery, i.e. short exercise time 3x as likely to have prolonged recovery (odds ratio: 3.1) and every 1 point increment on M-BESS 2x increased risk for prolonged recovery. ROC	The findings from this study indicate that graded exercise testing during the subacute phase can help to predict recovery trajectory, such that <9 minutes of exercise on adapted Bruce protocol is associated with prolonged recovery. Balance impairments also provide insight into the recovery trajectory. Incorporating a graded exercise test along with clinical tests could help providers more safely guide treatment and appropriately tailor interventions for a patient following a concussion.

					of both variables had a high predictive power (AUC 92.8%), 89.3% sensitivity, 83.1% specificity, 81.5% PPV, and 90.8% NPV	
Authors: Marshall CM, Chan N, Tran P, DeMatteo C. **Title:** The use of an intensive physical exertion test as a final return to play measure in concussed athletes: a prospective study **Year:** 2018 **Country of Study:** Canada **Design:** Prospective Cohort	Athletes from various levels of sport recovering from a concussion who were attempting to be medically cleared to RTP; Data for this study extracted in Feb. 2017 from 87 Complete Concussion Management Inc (CCMI) **Location:** Partnered Complete Concussion Management Inc (CCMI) clinics across Canada	**Inclusion:** Ages 13-25 yo with concussion; To be eligible for the GGT or modified GGT (mGGT) an athlete must have completed all RTL and non-contact RTP steps per international guidelines No exclusion criteria provided.	**Measures:** Primary: examine the pass/fail rate of athletes who had completed all RTL and RTP steps, who were asymptomatic, and hoping for RTP clearance. Date the participant passed the GGT or mGGT was considered the official RTP date. At initial clinical assessment the following were reported: total symptom number, total symptom severity score on SCAT3, any history of anxiety and/or depression. **Time Frame**: review was conducted to examine data collected between Jan 2016 and Feb 2017. Data for this study was extracted in Feb 2017 from 87 CCMI partnered clinic locations.	Participants in the study had completed all RTL and non-contact RTP steps, and were currently asymptomatic. They underwent the GGT or mGGT (while wearing HR monitor) at partnered CCMI clinics as part of RTP decision making. They were required to be asymptomatic through cognitive activity, return to school, the BCTT, and at least 2 sport-specific non-contact practices of increasing intensity. GGT – has two main test components designed to mimic a dynamic sporting environment (1^{st} = stationary cycling and 2^{nd} = plyometric activities). Subjects were asked throughout the test if they were experiencing any increase in sxs and GGT was stopped and considered a fail at first sign or report of any sxs (they continued with non-contact drill training and reattempted the test in the future). If they passed they	n = 759 (# athletes with complete data tested); mean age 15.5 yo (13-25 yo), 59.3% male, 40.7% female; a majority of the sample population sustained their mTBI playing ice hockey (44.7%). At initial assessment mean total sxs number = 10.56 and mean total sxs severity score on SCAT3 = 27.88; 46.5% did not have any prior concussions; 85.4% passed the test on the first attempt and a majority of subjects performed the mGGT (88.3%). No significant association was found between pass/fail rate and sex, MOI, depression, bike used, test type, age, # of concussions, or GGT attempts, but there was a significant relationship between anxiety and pass/fail rate. Significant difference was found in mean initial sxs severity scores between those who passed and those who failed on first attempt.	The findings from this study indicate that the GGT/mGGT may offer further assessment of "physical and physiologic constructs" not present in the BCTT. These constructs, which challenge the vestibular and oculomotor systems and anaerobic capacity, may offer a more realistic picture of the "dynamic sporting environment" and therefore give a more complete understanding regarding one's current recovery state. Symptoms at initial presentation are significant in predicting recovery time. The GGT and other symptom-provoking dynamic exercise tests should be studied more extensively.

				underwent physical and cognitive re-testing. The mGGT was administered to the younger/lower level athletes.	Previous diagnosis of anxiety, younger age, and female sex predicted a prolonged RTP time.	
Authors: Porter SJ, Johnson DE **Title:** Clinical Use of the Automated Neuropsychological Assessment Metrics TBI-Mil Expanded Battery in Evaluating Concussion Recovery: A Retrospect-ive Study **Year:** 2020 **Country:** USA **Design:** Restrospect ive Study	U.S. Navy Midshipmen (MIDN) who had sustained a mTBI and were now physiologi-cally asymptom-atic and medically cleared (n=508); age range = 17-26 yo; 35.6% female **Location:** United States Naval Academy (USNA)	**Inclusion:** Not explicitly provided. MIDN who had sustained a mTBI and were symptom free. ANAM4 performance reports were examined to ensure validity criteria was met (effort index ≤9, accuracy of scores >56%, none of normative scores ≥6 SD above mean). **Exclusion:** Subjects which failed to present for neurocognitive postinjury assessment within 30 days of being classified as asymptomatic.	**Measures:** -ANAM4 TME– modules designed to measure: attention, processing speed, working, short-term, and delayed memory, cognitive efficiency, response inhibition, visuospatial processing -SCAT 3 -BESS *Page 3 of article has criteria needed to determine return to neurocognitive baseline* **Time Frame:** Baseline neurocognitive assessments collected between 2013 and 2015. MIDN that did not meet all return to neurocognitive baseline criteria postinjury repeated the battery every ~24-48hr.	MIDN were referred for a neurocognitive assessment and administered the ANAM4 TME (All had been administered the ANAM4 when they entered USNA.) Performance reports were generated to ensure validity criteria was met. Criteria was used to determine if MIDN's post concussion evaluation was clinically deviant from baseline, indicating they had not returned to neurocognitive baseline. Results from 1st postinjury ANAM4 used to allocate individuals to group 1) returned to neurocognitive baseline (n=380) OR group 2) had not returned to baseline and subsequent testing was initiated (n=128). RCI for ANAM4 was used to compare baseline and postinjury assessments. Each module in ANAM4 had an RCI.	In group 1 there was a statistically significant difference between time from injury to asympto-matic status and gender (males 14.09 days, females 21.86, P<0.001). Statistically significant difference between gender and time until symptom free was found for group 2 (males 14.96 days, females 21.25, P=0.007). No significant difference between two groups' time to recover found (time between injury and 1st ANAM4). 128 of 508 MIDN determined to have not returned to neuro-cognitive baseline. Analysis of group 2 indicated an ~time to recover based on RCI criteria (RCI ≥ -1.64 indicated return to baseline ~9 days after postinjury assessment, RCI 2(+) ≥ -1/25 ~6 days to return to baseline.	The results from this study indicate that despite all MIDN previously reporting they were asymptomatic, many had not returned to neurocognitive baseline. Inclusion of the ANAM4, a neurocognitive assessment, in RTD protocols may provide a more accurate clinical picture when determining if a patient has fully recovered from a concussion. Providers should additionally consider that females may require additional recovery time for resolution of physiological symptoms. Higher level studies with a control group are needed.
Authors: Haider MN, Johnson	Student athletes with remote history of	**Inclusion:** Ages 13-24 years; physician or clinician diagnosed	**Measures:** -HR - R-R interval (RRI)	Participants completed a demographics questionnaire, the PCSS, and information regarding	Results for 30 subjects analyzed. (CH n = 9, CN n = 21). Median # of years since mTBI in CH	Based on the study results, history of a concussion in student athletes may result in

BD, Horn EC, et al. **Title:** Blunted Cardiac Parasympathetic Activation in Student Athletes With a Remote History of Concussion: A Pilot Study. **Year:** 2020 **Country:** USA **Design:** Retrospective nested case-control	SRC (Concussion History - CH group) and those with no lifetime history of a SRC (Concussion Naïve - CN group) **Location:** University Laboratory	concussions; CH group – healthy male and female high school or college aged athletes with remote hx of a concussion >1 year ago; CN group – same demographics but had never experienced a concussion **Exclusion:** taking medications that could affect ANS function; hx of concussion within the past year; persistent mTBI symptoms; lifetime hx of moderate to severe brain injury; lifetime history of >3 concussions	Root mean square of successive differences (RMSSD) of RRI High frequency (HF) and low frequency to HF (LF:HF) ratios **Time Frame:** Student athletes were retrospectively identified and were test at the university laboratory (1 time visit).	current sport participation. All subjects refrained from alcohol, caffeine, and exercise 12 hours prior to their visit, and refrained from food 2 hours before. A 3-lead ECG was set up and participants laid in the supine position in a quiet environment for 10 minutes before the face cooling (FC) test. During the FC test a pliable plastic bag with ice water was placed on the forehead, eyes, and cheeks for 3 min.	group was 2 years. At baseline CH had lower HR and higher LF:HF ratio at 1 minute than CN. CH and CN groups responded differently to FC test, such that mean HR increased in CH group during minutes 1-2 (+8.9% change), but declined in the CN group (-7.5% change). No difference over time between the two groups and no effect of sex for RRI. A difference over time for RMSSD percent change from baseline was found between groups (+31.8% in CH and +121.8% in CN). No significant between group differences were found for RRI, HF, or LF:HF ratio over time.	blunted cardiac parasympathetic response to the FC test, despite having returned to sports and school without limitations. Findings indicate a concussive injury has implications on cardiac parasympathetic activity and thusly the ANS (HR increased in CH group during first 2 minutes while it decreased in CN). This ANS dysfunction a year or longer after the concussive injury suggests cardiac autonomic dysfunction may persist longer than expected and should be further examined. The findings from this convenience sample may not be generalized to all student-athletes.
Authors: Darling SR, Leddy JJ, Baker JG, et al. **Title:** Evaluation of the Zurich Guidelines	Adolescent athlete patients of the University at Buffalo Sports Medicine Concussion Management	**Inclusion:** Adolescent athletes (aged 13-19 yo) who sustained a concussion during a sporting event (observed by a team trainer) and were assessed by sports medicine physician	**Measures:** Primary – degree of success in RTP (ie RTP with or without return of concussive symptoms) Secondary – return to school with or without symptoms	Initial assessment included cNP testing and the SCAT-2. Once the athlete was asymptomatic they underwent final cNP testing and the BCTT. Athletes who were able to exercise until voluntary exhaustion on the BCTT without symptom	75.2% were male (most common sports played were football n=37, ice hockey n=22, and wrestling n=11 and soccer for females). Females took substantially longer to achieve “asymptomatic state” (mean days = 22	Results from this study indicate the benefit in administering treadmill testing and the Zurich guidelines to safely return the athlete to sport. The findings indicate cNP performance did not

and Exercise Testing for Return to Play in Adolescents Following Concussion **Year:** 2014 **Country:** USA **Design:** Retrospect-ive chart review and follow up	Clinic (n=117, male n=88, female n=29) **Location:** University Sports Medicine Concussion Clinic	with concussion management experience. All athletes seen at 1 concussion clinic during a 3-year period (2010-2012) were included as long as there was at least 2 months from time of RTP to follow up. Exclusion criteria not provided.	**Timeline:** All athletes were seen at 1 concussion clinic during a 3 year period (2010-2012). Days from concussion to initial evaluation ranged from 0-56 and days from concussion to passing the BCTT ranged from 3-108 days.	exacerbation were allowed to RTP following the stepwise Zurich guidelines. Any athlete that reported symptom recurrence was instructed to notify the concussion clinic, withdraw from the sport, and return for a reassessment. The first 65 athletes were assessed with the ANAM and subsequent athletes were assessed with the ImPACT. cNP testing was performed prior to the BCTT.	and for males = 14) Substantial range in severity of mTBI and in number of days between injury and initial physician assessment. All athletes RTS in the week following a successful completion of the BCTT and none experienced exacerbation in sport during the 2 mo follow up (n=91 with phone call). 42.9% had difficulty in readjusting to the classroom (difficulty concentrating); 31.7% had 1(+) previous mTBI and 20.5% had 1 previous mTBI; 53.9% of those assessed with the ANAM and 41% of those assessed with the ImPACT had at least 1 borderline score on day they passed the BCTT. None of the subtest variables on the ImPACT or ANAM were significantly correlated with either outcome.	relate to RTP success and neither the ANAM or ImPACT predicted school related issues. There is concern that some athletes may not have put forth full effort and there was no baseline data to compare to.
Authors: Rutschmann TD, Miutz LN, Toomey CM, Yeates KO, Emery CA,	Individuals referred for an exertional treadmill test as part of a larger cohort study at the Acute Sport Concussion	**Inclusion:** 13-60 years old; confirmed diagnosis of a SRC by a sports medicine physician; signed Physical Activity Readiness Medical examination form by	**Measures:** Scores on the PCSS from SCAT5 immediately, 1-4h, and 6-12h following completion of the BCTT; change in PCSS scores ≥4 points operationally defined	Prior to the BCTT subjects completed demographic and injury related questionnaires, the PCSS, and "overall condition" rating. Height, weight, resting HR, and BP info was collected by an exercise physiologist.	22 of the 45 subjects had a previous hx of mTBI. Most commonly reported sxs during BCTT were headache (48.9%), dizziness (44.4%), and pressure in head (26.7%). 46.7% reported a single sxs and 53.3% reported	The results of this study indicate the usefulness of exertional testing to assess physiological functioning following a concussion to help determine readiness for RTS. Frequently,

Schneider KJ **Title:** Changes in exertion-related symptoms in adults and youth who have sustained a sport-related concussion. **Year:** 2020 **Country:** Canada **Design:** Prospective case-series	Clinic (ASCC); 21 males and 24 females met inclusion criteria **Location:** University of Calgary Sport Medicine Center	study physician; participant able and willing to perform a graded treadmill test **Exclusion:** concussion was not sport-related; resting HR > 99 beats/min and/or BP >144/94 mmHg; contraindications to exercise testing (cardiac, respiratory, orthopedic contraindications); pre-exertional "overall condition" score >6/10	as symptom change; participants classified as improved, no change, or worsened **Time Frame:** Individuals which met the inclusion criteria were recruited from Dec. 20 2017 to August 31, 2018. Subjects participated in a single exertion testing session and reported symptoms via an email survey at 1-4h and 6-12h following testing.	PCSS ratings completed immediately before and 5 minutes following the BCTT and sxs reported again 1-4h and 6-12h following exertional testing. A modified version of the BCTT was performed and subjects wore a polar HR chest strap. Borg RPE and HR were recorded every minute during testing and BCTT was terminated once symptom-limited threshold (≥2 point increase) or voluntary exhaustion reached	multiple. 14 of 24 females and 13 of 21 males reported an increase in PCSS immediately following the BCTT. 1-4h after testing 5 of 10 males and 5 of 14 females that completed the PCSS had elevated sxs, and at 6-12h 3 of 17 males and 5 of 16 females reported increased sxs severity scores. Of the 33 subjects which provided sxs ratings at 6-12h, 6 improved, 20 returned to pre-exertion scores, and 8 had worsened. Those with greater pre-exertion PCSS had more variable changes in scores following the BCTT.	individuals experience exertional difficulties following a concussion. The findings from this study suggest that while exertion testing may elicit symptoms, symptoms often return to pre-exertion level within 12 hours. Length of time until symptom resolution following an exercise task may provide insight into one's predicted recovery, but larger studies with more formal monitoring and lower potential of selection bias are needed.
Authors: Morissette MP, Cordingley DM, Ellis MJ, Leiter JRS. **Title:** Evaluation of Early Submaximal Exercise Tolerance in Adolescents with Symptomat	Symptomatic sport related concussion (SSRC) group recruited from Pan Am Concussion Program in Winnipeg, Manitoba, Canada (n=34) and healthy controls (HC) were a sample of	**Inclusion:** **SSRC group** – physician diagnosis of concussion using definition by McCrory et al, age 13-19 yo, symptomatic at time of graded aerobic exercise challenge **HC group** – physically active adolescents 13-19 yo, no contraindication to exercise (based on Physical Activity	**Measures:** Assessed at test and test termination -HR -VO_2 -VCO_2 -V_E -RPE at matched exercise intensities in adolescents with PCS compared with healthy controls **Time Frame:** Subjects recruited between June 2016 and July 2018	Demographic information and resting HR and BP were collected. Resting post-concussion sxs evaluated with PCSS; Subjects fitted with mouthpiece attached to metabolic cart for collection of cardiorespiratory variables. Participants then completed the BCTT with HR, RPE, and symptom status reported every minute and cardiorespiratory data collected every minute as	Age of patients in groups was not significantly different and time to follow-up was similar for genders. SSRC patients had higher total number of sxs and severity of sxs at baseline. No group differences in resting cardiorespiratory variables (HR, SBP, DBP) found between groups. SSRC group reached a lower peak stage during BCTT compared to HC, along with a lower peak RPE	The results of this quasi-experimental study indicate that individuals who have experienced a SRC may demonstrate similar cardiorespiratory response to graded exercise as healthy controls, but may rate their RPE higher despite working at the same set grade and speed. This suggests that individuals who have sustained a

ic Sport-related Concussion **Year:** 2020 **Country:** Canada **Design:** Quasi-experimental non-randomized study	convenience (n=40) **Location:** Multidisciplinary pediatric concussion program	Readiness Questionnaire) **Exclusion:** Patients with history of moderate or severe TBI or traumatic findings on previous neuroimaging studies; pregnancy; other contraindications to exercise testing		well. BCTT was terminated if subject became excessively fatigued or experienced a symptom-limited threshold (increase in ≥2 points). Peak HR, BP, PCSS, and cardiorespiratory data recorded upon termination. Data compared with healthy controls.	and lower relative peak VO_2, VCO_2, and V_E. SSRC group had significantly lower peak SBP and higher peak DBP. Male SSRC patients exhibited lower peak HR and peak $\%HR_{max}$ compared with female SSRC patients, and overall females reached lower BCTT stages. HC females reached lower peak relative VO_2, VCO_2, and V_E. No group differences for change in cardiorespiratory variables was found, but SSRC subjects demonstrated higher RPE compared with HC. They also terminated BCTT at mean of ~14 min on average compared with a mean of ~20 min in HC.	concussion may have limited exercise tolerance. The exercise parameters in this study may have not been challenging enough to elicit differences in cardiorespiratory variables, supporting the need for larger longitudinal studies with greater intensity exercise tests.
Authors: Lesniak E, Ramsey KG, Brady C,Beydoun HA, Johnstone B. **Title:** Predicting military readiness using objective	Study sample drawn from data of SMs previously evaluated at an outpatient military TBI rehabilitation clinic **Location:** Fort Belvoir Intrepid Spirit Center	**Inclusion:** SMs who received neuropsychological evaluation at an outpatient military TBI rehabilitation clinic between 2013 and 2018 **Exclusion:** reading score at least 10 points below their Full-Scale IQ	**Measures:** Outcome measures – -Military work status: RTD, medically retired-disabled (MEB-disabled), or retired from military based on years of service -Relative degree of decline scores Predictor measures – -Wechsler test of adult reading (WTAR)	Scores for a number of neuropsychological tests were used to determine how objective neuropsychological measures and subjective measures of neurobehavioral difficulties were related with a SMs ability to RTD following mTBI. The purpose of this study was to identify potential predictive indicators that	n=113; 85% of SMs categorized as having mTBI and 15% diagnosed with moderate or severe TBI. Most reported history of multiple mTBIs. Average time since injury until neuropsychological evaluation was 9.58 years. 41 RTD, 28 MEB-disabled, 44 retired. Scores for absolute level of functioning and	The findings from this retrospective study suggest absolute level of functioning on standard neuropsychological indices (scores compared to groups of similar demographic characteristics and reported as above average, average, or below average) may help better predict

and subjective indices of neuropsychological impairment in service members with mild traumatic brain injury **Year:** 2020 **Country:** USA **Design:** Retrospective analysis of existing data from outpatient TBI clinic			-Weschler adult intelligence scale-fourth edition (WAIS-IV FSIQ, WMI, PSI) - California verbal learning test-second edition (CVLT-II) -NSI **Time Frame:** SMs had undergone a neuropsychological evaluation between 2013 and 2018	could inform ability to RTD upon recovery. Researchers hypothesized absolute level of neuropsychological functioning and relative degree of decline would be significantly related to outcomes and would interact to impact outcomes. They also hypothesized subjective measures of neuropsychological impairment would be better outcome predictors than objective measures.	relative degree of decline were significantly different for RTD group compared to disabled and retired groups (WAIS-IV WMI and FSIQ, and NSI total scores), indicating higher intelligence and working memory and fewer subjective complaints. Absolute scores on the WAIS-IV FSIQ, WMI, and PSI, and NSI independently predicted work status. Relative decline scores were not predictive of military work status in any of the models. Both disabled and retired SMs had lower absolute functioning in working memory, and higher subjective complaints were associated with MEB-disabled, while higher absolute delayed recall was associated with retirement.	RTD outcome in SMs who have sustained a mTBI. The results suggest the importance of assessing cognitive abilities and subjective complaints to predict ability to RTD, but futures studies are needed to discern the most appropriate subjective and objective indices associated with poor outcomes in this population.
Authors: Mohler S, Elbin RJ, Ott S, et al. **Title**: How long after maximal physical exertion should baseline	Participants recruited from a large university **Location:** southeast U.S.	**Inclusion:** healthy, college aged athletes; 18–26 yo and had to have at least moderate levels of physical activity according to responses on the International Physical Activity Questionnaire Long	**Measures:** -VO2 max -Computerized neurocognitive testing aka CNT (ImPACT) -Compliance assessments: hydration status, diet, sleep, fluid consumption, physical activity, caffeine, over the counter drugs,	Participants completed 4 randomly ordered (counterbalanced) experimental trials with a minimum of 7 days between sessions (baseline, immediate recovery visit, 10-minute recovery visit, 20-minute recovery visit – indicating recovery time between end	Final sample = 30 participants (M = 21.87 +/- 2.29 years), 63.3% male, 70% highly active. 5 of the 30 had a hx of concussion (>6 mo prior). No significant within subjects main effects across various trials for hydration, sleep duration, and 24 hr caloric	The findings from this study indicate it may be more appropriate for clinicians to wait more than 20 minutes after a MPE before assessing baseline symptoms. The study findings indicate physical exertion does not negatively impact

computerized neurocognitive testing and symptom assessment be administered? **Year:** 2021 **Country:** USA **Design:** Randomized, repeated measures, counterbalanced design		Form (IPAQ); required to receive medical clearance by a licensed sports medicine professional prior to participation **Exclusion:** learning disability, ADHD, psychological disorder (e.g., clinical depression/anxiety), history of substance abuse, non-English speaking, or a concussion within the last six months were excluded	supplements, alcohol (24 hour intake form) -maximal graded exercise treadmill protocol -Self-reported effort assessment (4 point Likert scale) **Time Frame:** minimum of seven days between sessions (4 trials)	of maximal physical exertion (MPE) protocol and beginning of CNT test.) CNT administered following maximal physical exertion (MPE) with assigned recovery periods mentioned above. During control trial MPE protocol not performed.	consumption. Researchers found significantly higher HRs at the start of CNT following immediate recovery interval ($p<0.001$) and significantly lower HRs during control trial. Significantly higher processing speed scores found during 20-minute recovery interval trial compared to control trial. Significantly greater total symptom scores ($p<0.01$) found following all trials with preceding MPE protocol (immediate, 1-minute, 20 minute intervals) when compared to control trial.	neurocognitive scores when adequate rest interval provided. Providers/clinicians should be aware of the impact of physical exertion on baseline symptom scores. Limitations: may not be able to extrapolate results to other neurocognitive tests; order of 6 neurocognitive subtests fixed earlier subtests may be more influenced by fatigue
Authors: Sullivan KA, Hills AP, Iverson GL. **Title:** Graded Combined Aerobic Resistance Exercise (CARE) to Prevent or Treat the Persistent Post-	Characteristics of exercise programs for persistent post-concussive syndrome were studied. *Exercise as Primary or Adjunctive Treatment* • Evidence that physical activity helps to improve outcomes in people with co-occurring injuries to their mTBI. • Exercise can help to reduce anxiety, depression, stress, and improve self-esteem and sleep. • Exercise is associated with symptom reduction and functional gains in those who have persistent symptoms following a mTBI. *Safety Considerations* • Research indicates low intensity and possibly moderate intensity exercise is safe for individuals with persistent mTBI symptoms. • No evidence to indicate low intensity non-contact exercise is unsafe for individuals with persistent mTBI symptoms, but safety features should be in place, such as discontinuation rules and threshold rules. *The Potential Benefits* • Literature suggests that exercise can be beneficial for patients with persistent PCS, measured through patient report questionnaires. *Evidence for the Proposed Mechanism* • There is still speculation regarding the mechanism by which exercise might benefit individuals with PCS, but it has been speculated that the mechanisms are associated with increased parasympathetic activation, decreased sympathetic activation, and improved cerebral blood flow to combat physiologic dysfunction. *Exercise vs Non-exercise Approaches*					

concussion Syndrome **Year:** 2018 **Country:** Australia **Design:** Review	• There is insufficient research comparing the benefit of an exercise-based approach to other strategies for individuals with persistent mTBI symptoms (pharmacological and psychological interventions). *Target Groups* • A majority of the exercise-based interventions have been studied in SRC adolescent and young adult populations, which is only a subset of the mTBI population and limits generalizability. *Research Design Considerations* • Most of the research on this topic has used a retrospective design, limiting the quality of evidence and many of studies did not incorporate a control group or blinded outcome assessment. • Many of the studies did not include information regarding adherence and verify dose of activity consumed. A majority of the studies included potential and significant biases. *Forms of Therapeutic Exercise* • Most studies have examined aerobic exercise (treadmill and cycling based programs) to a sub-symptom threshold (% max HR before symptoms), but few have used multi-modal interventions or a PT treatment component. • The appropriate timing, duration, and intensity of exercise programs to benefit individuals with PCS is still unknown. *Graded Combined Aerobic Resistance Exercise Circuits for People with mTBI* The reviewers propose future research regarding exercise-based approaches for the treatment of individuals with PCS should focus on combined aerobic resistance exercise with a circuit-based model. They suggest for the initial trial of these exercise programs to be supervised and for the exercise to be individually prescribed by a qualified professional.					
Authors: Coffman CA, Kay JJM, Saba KM, et al. **Title:** Predictive Value of Subacute Heart Rate Variability for Determining Outcome Following Adolescent Concussion **Year:** 2021 **Country:** USA **Design:** retrospectiv	Youth screened for concussion; 55 youth (12-17 years old) were eligible and included in the final analyses per inclusion/ exclusion criteria **Location:** participants recruited from a local pediatric sports medicine clinic	**Inclusion:** adolescent patients who initially received a diagnosis of concussion during subacute evaluation (3-15 days) and returned for a follow-up post-acute evaluation within 60 days **Exclusion:** medical histories known to further alter the outcome following concussion and cardio-autonomic function (≥ 2 previous concussions, learning/develop-	**Measures:** -Demographics/Health Information Survey -Heart Rate Variability (HRV) through EmWave Pro Plus pulse plethysmograph ear sensor -Rivermead Post-Concussion Symptoms Questionnaire (RPQ) -Beck Youth Inventory Second Edition – Depression Scale (BYI-2) -Behavior Rating Inventory of Executive Function (BRIEF-P) -CogState Brain Injury Testing Battery **Time Frame:**	At initial evaluation concussion was confirmed by physician associated with study. Participants returned 3 weeks after initial eval for follow up evaluation. Short term HRV metrics obtained under resting conditions and physiological stress. More specifically, HRV metrics collected during 5 minutes of rest (seated position) and a 1-minute HRV recording taken during physical exertion (isometric handgrip contraction). At each time points self-reported clinical and depressive symptoms, neurobehavioral function,	Age (years) 14.5 +/- 1.4; 56.4% male, 43.6% female; Cause of injury: 67.3% sport or recreation, 20% MVA, 12.7% other (fall, accident); Days from concussion at subacute eval (9.0+/-4.5) and post-acute eval (29.2+/-10.2); results from paired-sample t-tests indicate clinical and depressive symptoms significantly decrease between subacute and post-evaluation ($p<0.001$) While measures of neurobehavioral functions did not improve over time, measures of cognitive performance significantly improved (p	This study highlights the necessity of validating predictive tools for determining adolescent concussion outcomes. Findings from this study indicate subacute HRV metrics may be used as a predictive biomarker in identifying potential neurological dysfunction following injury and possible late cognitive outcomes in adolescents. Clinical symptoms and neurobehavioral function alone in the subacute time period

e analysis of data extracted from larger study		mental disorder, psychiatric/psychological condition, heart condition, neurological condition, asthma)	Subacute evaluation (3-15 days post injury) and post-acute evaluation (15-60 days following injury)	and cognitive performance information collected.	<0.05). Multivariate regression analyses found concussed adolescents with greater HRV at rest reported lesser somatic symptom severity at post-evaluation. Regressive analysis also found significant associations between clinical symptoms, neurobehavioral function, and cognitive performance at the subacute evaluation.	may not predict future symptom severity. Limitations: preinjury baseline measures not captured, did not include an objective measure of cardiorespiratory fitness or account for individual differences in physiological maturity. Recommend future research across larger variety of populations
Authors: Popovich M, Almeida A, Lorincz M, et al.. **Title:** Does Exercise Increase Vestibular and Ocular Motor Symptom Detection After Sport-Related Concussion ?. **Year:** 2021 **Country:** USA **Design:** cross-	Athletes between the ages of 10 and 18 years diagnosed w/ concussion were prospectively recruited **Location:** participants recruited from multidisciplinary sport concussion clinic at tertiary care center	**Inclusion:** Athletes 10-18 yo with concussion and receiving clinical care within 30 days of injury **Exclusion:** receiving care for their concussion beyond 30 days of injury, if they were assessed to have recovered from their concussion, or if they had any medical contraindication to exercise (cardiovascular, respiratory, or musculoskeletal comorbidity) that would preclude safe participation	**Measures:** -VOMS total symptom score -Likert scale rating symptoms (presence of headache, dizziness, nausea, fogginess) on a 0 to 10 point Likert scale at baseline and following each component of the assessment -Near Point Convergence (NPC) distance measured -Heart rate **Time Frame:** One time visit within 30 days of injury	Participants in this study participants in VOMS assessments completed at rest and immediately after a supervised exercise challenge (SEC). VOMS items performed in following order: smooth pursuits, horizontal saccades, vertical saccades, near point of convergence (NPC), horizontal vestibulo-ocular reflex (VOR), vertical VOR, and visual motor sensitivity. Pt reported symptoms on Likert scale. Symptom score changes used to determine symptom provocation for individual VOMS items. Symptom score increase of 2+ points from baseline considered positive symptom provocation for	36 athletes (58.3% male) included. Median age 15 yrs. Median number of days from concussion to study visit 12.5 (range 3-30). Researchers found significant increases in post-SEC symptom provocation scores compared with pre-SEC scores for all VOMS assessment items. Mean post-SEC NPC distance was significantly greater compared with pre-SEC. During pre-SEC testing 21 participants identified as positive in at least 1 VOMS item, but at post-SEC 29 participants identified (identified participants previously negative on pre-SEC VOMS). VOMS assessment items that	The findings from this study indicate the benefit in implementing SECs prior to VOMS testing to better detect vestibular and ocular motor symptoms that may not be present with VOMS assessment at rest. VOMS assessment at rest may miss possible vestibular-ocular dysfunction provoked by physical exertion and suggest ongoing concussion deficits that may change treatment plan and return to play course of action. The findings indicate SECs may help better inform

sectional study				item. Each participant engaged in standard SEC protocol guided by athletic trainer in a gym space at the clinic: 16 min stationary bike workout (8 2 minute intervals followed by 2 minute sitting rest period), dynamic medicine ball exercises (2 lb ball). Symptoms scores recorded at 2 minute intervals throughout bike exercises and after each set of medicine ball exercises. Safety stopping rules in place if pt's symptoms increased.	produced positive result in post-SEC included smooth pursuits, vertical saccades, NPC symptoms, visual motion sensitivity, and horizontal VOR. Item with largest change from negative in pre-SEC to positive in post-SEC was smooth pursuits.	post-concussion trajectories. Limitations: majority of participants were male and findings may not be applicable to nonathlete population.

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