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The Additive Benefits of Aerobic Exercise and Cognitive Training Postconcussion: Current Clinical Concepts

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Concussion induces the rapid onset of a short-lived neurophysiological disturbance that often results in autonomic nervous system dysfunction. This dysfunction affects both cardiovascular functioning and higher cognitive processing, inducing postconcussion clinical symptoms (somatic, cognitive, or emotional or a combination) and functional disturbances (impaired balance, cognition, and visual-vestibular performance). Current concussion rehabilitation paradigms using aerobic exercise may improve concussion symptoms. Additionally, cognitive training–focused rehabilitation interventions may enhance cognitive function postinjury. Though aerobic exercise and cognitive training–based concussion rehabilitation are successful independently, the multifaceted nature of concussion suggests the potential benefit of integrating both to improve concussion outcomes and clinician implementation. To support this clinical recommendation, we critiqued the existing research in which authors investigated aerobic exercise and cognitive training as postconcussion rehabilitation modalities, identified keys gaps in the literature, and proposed a practical clinical recommendation to integrate both modalities during concussion rehabilitation.

Key Words: multifaceted rehabilitation, mild traumatic brain injury, sport-related concussion

Key Points

- When used independently, aerobic exercise and cognitive training improve postconcussion outcomes.
- Integrating aerobic exercise and cognitive training postconcussion may benefit an athlete's injury outcomes, specifically neurophysiological and autonomic nervous system function outcomes.
- Integrating aerobic exercise and cognitive training postconcussion may help to ease the burden on the athlete and athletic trainer throughout the postconcussion rehabilitation period.

Sport-related concussion is a major health concern for athletes at all levels of competition.[1] Concussion induces the rapid onset of a typically short-lived neurophysiological disturbance that often results in autonomic nervous system (ANS) dysfunction.[1–4] This dysfunction affects both cardiovascular functioning[2,4] and higher cognitive processing,[5,6] inducing postconcussion clinical symptoms (somatic, cognitive, or emotional or a combination) and functional disturbances (impaired balance, cognition, and visual-vestibular performance).[1,7] Currently, athletic trainers (ATs) monitor concussion recovery by tracking concussion evaluations and the return-to-play process.[8] Furthermore, return-to-play progressions facilitate a safe reintroduction to sport-specific activity and largely rely on the athlete's symptom exacerbation and functional status.

Until the 2016 Concussion in Sport Group consensus statement,[1] concussion management focused on complete rest until postconcussion symptoms returned to baseline. However, researchers have indicated that physical and mental rest beyond 24 to 48 hours postconcussion may prolong recovery when compared with a more active approach toward rehabilitation.[9–11] Specifically, favorable results were demonstrated after aerobic exercise during acute concussion recovery,[12–19] in those with persistent concussive symptoms (ie, the presence of symptoms beyond the typical recovery timeframe of 10–14 days for adults and $\leq$4 weeks for adolescents),[15,20–24] and in those with a concussion history.[25] However, due to the multifaceted nature of concussion, aerobic exercise may not directly address all impairments seen postinjury. In particular, postconcussion neurophysiological changes affect higher cognitive processing,[5,6] resulting in impaired cognition.[1–4]

Cognitive training–based rehabilitation modalities have been useful in improving overall cognitive function postconcussion, notably in military populations.[26–31] Yet like aerobic exercise, this modality does not address all impairments that may be seen postconcussion.

In this current clinical concept paper, we reviewed the current literature surrounding the use of aerobic exercise and cognitive training postconcussion. Articles were identified via separate searches on PubMed for both postconcussion rehabilitation topics: (1) aerobic exercise and (2) cognitive training. The search was completed in April 2022 and used the following inclusion criteria: (1) full-text, peer-reviewed articles, (2) participants with sustained mild traumatic brain injury or concussion, and (3) primary data collection (ie, randomized controlled trial or cohort study). To investigate the use of aerobic exercise for concussion rehabilitation, we added the requirement of aerobic exercise as a postconcussion rehabilitation mechanism in the study design. To explore the use of cognitive training as a tool to improve concussion outcomes, we added the requirement of cognitive training as a postconcussion rehabilitation mechanism in the study design. Articles were included based on clinically relevant content. We summarized the protocols and outcomes based on the reviewed manuscripts. Here, we provide clinicians with information regarding current and emerging evidence on implementing aerobic exercise and cognitive training. Also, we outlined a practical clinical recommendation regarding the integration of aerobic exercise and cognitive training postconcussion to further improve neurophysiological disturbances (specifically ANS functioning) and clinical outcomes. Moreover, we described how the proposed clinical recommendation aims to decrease the clinical burden on the AT throughout the concussion recovery process. The Strength of Recommendation (SOR) Taxonomy[32] was used to grade the strength of evidence for each recommendation.

AEROBIC EXERCISE–BASED CONCUSSION REHABILITATION

Aerobic exercise interventions postconcussion have been successful in improving symptom resolution in individuals with acute concussion[12–17,19] and persistent concussion symptoms (ie, presence of symptoms beyond the typical recovery timeframe of 10–14 days for adults and $\leq$4 weeks for adolescents).[15,20–24] Additionally, researchers[25] have suggested that aerobic exercise may improve cognitive function in those with a concussion history. The basis for exercise during recovery, as outlined in the pivotal paper "Exercise is Medicine for Concussion,"[33] is that aerobic exercise improves ANS regulation,[34] neuroplasticity,[35] cognitive function,[36] and quality of life[37] and attenuates cognitive impairment.[38] As such, we discuss the current clinical implementation of aerobic exercise–based concussion rehabilitation and propose future implications of connecting current findings to restoring neurophysiological (ANS) function postconcussion. A summary of the aerobic exercise–based studies is provided in Table 1.

Aerobic Exercise for Acute Concussion Rehabilitation

The authors of several studies investigating the use of aerobic exercise acutely postconcussion have reported improved concussion outcomes[14,19] or no difference in symptom resolution.[12,17] Other researchers applied outcome measures including concussion symptoms[12,14,17,19] and clinical recovery identified by a blinded study physician.[14,19] Details regarding each study are outlined in the following paragraphs.

In acutely concussed adolescents, Leddy et al[14,19] compared how aerobic exercise versus prescribed stretching improved concussion recovery. The aerobic exercise group was instructed to perform daily at-home aerobic exercise on a stationary bike or treadmill for at least 20 minutes per day. Participants' intensity goal was 80% or 90%, respectively, of the heart rate achieved during their baseline exercise tolerance assessment, the Buffalo Concussion Treadmill Test (BCTT).[13] The BCTT, a validated and safe protocol for assessing exercise tolerance in patients with concussion, is a 20-minute protocol in which participants walk on a treadmill as intensity increases and concussion symptoms are monitored each minute.[13] Individuals in the aerobic exercise group recovered (ie, symptom resolution to normal confirmed by a physical examination and the ability to complete the BCTT without symptom exacerbation) sooner than those randomized to the stretching protocol (median recovery of 13 versus 17 days, respectively).[14] In a more recent examination, Leddy et al[19] found that subsymptom threshold aerobic exercise had a beneficial effect on clinical recovery during the first 4 weeks postconcussion, with a 48% reduction in the risk of persistent postconcussion symptoms (SOR: A).

Conversely, in a collegiate student-athlete population, Maerlender et al[12] identified no differences in concussion symptom recovery between collegiate student-athletes randomized to aerobic exercise versus standard care (ie, normal daily activities only).[12] Those in the aerobic exercise group performed at light to moderate intensity based on their perceived exertion (defined as 0–6 on the Borg Rate of Perceived Exertion modified scale, which ranges from 0–10) rather than a physiological marker. Therefore, they may not have reached the exercise intensity necessary to promote neurophysiological recovery postconcussion. Furthermore, this study included student-athletes both immediately postinjury and beyond the typical 2-week recovery window. As such, they may have been at various stages of neurophysiological recovery, making it difficult to discern the effect of aerobic exercise on neurophysiological function. In adults with acute concussion, Varner et al[17] demonstrated no difference between the exercise and control groups in the proportions of participants with persistent concussion symptoms at 30 days or median change in concussion symptoms, visits to a health care provider, missed school or work days, or unplanned emergency department visits. Adults presenting to the emergency department within 48 hours of concussion were prescribed either 30 minutes per day of light aerobic exercise (intervention) or treatment as usual (gradual return to exercise after symptom resolution). Again, those in the intervention group were not asked to reach a target heart rate during activity. As such, these participants may have similarly failed to reach an exertion level intensity effective enough to target postconcussion ANS dysfunction. However, neither set of researchers encountered any safety concerns with moderate physical activity (SOR: A).

Investigators aim to determine the amount of aerobic exercise (ie, minutes per week) needed to improve concussion outcomes. In adolescents and young adults who were prescribed aerobic exercise acutely postconcussion, Howell et al[16] noted that participants who reported $<$100 minutes of exercise per week described greater symptom severity at the

Table 1. Aerobic Exercise–Based Concussion Rehabilitation Studies

Title	Authors	Year	Aerobic Exercise Intervention	Key Clinical Findings
"Early Subthreshold Aerobic Exercise for Sport-Related Concussion: A Randomized Clinical Trial"	Leddy et al[14]	2019	Daily, at-home aerobic exercise for 20 min on stationary bike or treadmill at 80%–90% of heart rate achieved during baseline exercise tolerance assessment	Aerobic exercise group recovered sooner than stretching placebo group (13 vs 17 d).
"Early Targeted Heart Rate Aerobic Exercise Versus Placebo Stretching for Sport-Related Concussion in Adolescents: A Randomised Controlled Trial"	Leddy et al[19]	2021	Daily, at-home aerobic exercise for 20 min on stationary bike or treadmill at 80%–90% of heart rate achieved during baseline exercise tolerance assessment	Aerobic exercise group saw 48% ↓ in persistent postconcussion symptoms risk.
"Programmed Physical Exertion in Recovery From Sports-Related Concussion: A Randomized Pilot Study"	Maerlender et al[12]	2015	Daily aerobic exercise on a stationary bicycle for 20 min at light to moderate intensity (Borg Rate of Perceived Exertion, 0–6)	No difference in recovery time for aerobic exercise vs standard care.
"A Randomized Trial Comparing Prescribed Light Exercise to Standard Management for Emergency Department Patients With Acute Mild Traumatic Brain Injury"	Varner et al[17]	2021	30 min of light aerobic exercise daily (ie, walking)	No difference between aerobic exercise and treatment-as-usual groups in proportion of participants with persistent concussion symptoms at 30 d or median change in concussion symptoms, visits to health care provider, missed school or work days, or unplanned emergency department visits.
"Influence of Aerobic Exercise Volume on Postconcussion Symptoms"	Howell et al[16]	2021	Aerobic exercise 5 times/wk for 20 min at 80% of maximum achieved heart rate at baseline exercise tolerance assessment	Participants who reported <100 min/wk of exercise had ↑ symptom severity at 1-mo study visit than those who reported ≥100 min/wk; those who completed ≥160 min/wk were less likely to report concussion symptoms.
"Aerobic Exercise for Adolescents With Prolonged Symptoms After Mild Traumatic Brain Injury: An Exploratory Randomized Clinical Trial"	Kurowski et al[20]	2017	At-home cycling 5–6 d/wk for 6 wk at 80% of duration that exacerbated symptoms during baseline exercise tolerance assessment	↑ Rate of returning to asymptomatic in aerobic exercise vs control group.
"Neurocognitive and Quality of Life Improvements Associated With Aerobic Training for Individuals With Persistent Symptoms After Mild Traumatic Brain Injury: Secondary Outcome Analyses of a Pilot Randomized Clinical Trial"	Gladstone et al[22]	2019	At-home cycling 5–6 d/wk for 6 wk at 80% of duration that exacerbated symptoms during baseline exercise tolerance assessment	Pre-post differences in ↑ cognition for those in aerobic exercise group and pre-post differences in ↑ self- and parent-reported quality of life for both groups.
"Structural Connectivity Related to Persistent Symptoms After Mild TBI in Adolescents and Response to Aerobic Training: Preliminary Investigation"	Yuan et al[24]	2017	At-home cycling 5–6 d/wk for 6 wk at 80% of duration that exacerbated symptoms during baseline exercise tolerance assessment	↑ Global efficiency, which directly correlated with reported concussion symptoms, in aerobic exercise group.
"Pilot Randomized Controlled Trial of an Exercise Program Requiring Minimal In-Person Visits for Youth With Persistent Sport-Related Concussion"	Chrisman et al[21]	2019	Daily aerobic exercise that began at 5–10 min and worked toward 60 min for 6 wk	Participant-reported concussion symptoms ↓ more rapidly in aerobic exercise vs stretching group.
"Subtle Long-Term Cognitive Effects of a Single Mild Traumatic Brain Injury and the Impact of a 3-Month Aerobic Exercise Intervention"	Larson-Dupuis et al[25]	2021	Aerobic exercise on stationary bicycle for 20–40 min, 3 times weekly, for 12 wk	↑ Cardiovascular fitness (ie, %$\dot{V}O_2$max) for those in aerobic exercise versus stretching control group; no difference in cognitive performance.

Abbreviation: TBI, traumatic brain injury.

1-month study visit than those who exercised >100 minutes per week. Furthermore, those who completed ≥160 minutes of exercise per week were less likely to report concussion symptoms at the 1-month study visit, a finding that may inform exercise dosage in future studies[16] (SOR: B).

Aerobic Exercise for Persistent Concussion Symptoms

Additionally, authors have evaluated the use of aerobic exercise to improve outcomes in those with persistent concussion symptoms (ie, the presence of symptoms beyond the typical recovery timeframe of 10–14 days for adults and ≤4 weeks for adolescents). Adolescents with persistent concussion symptoms (4–16 weeks postinjury) who were assigned to the aerobic exercise group showed a greater rate of improvement in postconcussion symptoms than those in the stretching group.[20] Throughout the 6-week study, participants completed an at-home cycling program 5 to 6 days per week at 80% of the duration that exacerbated symptoms during a baseline test. No intensity was specified. A significant group × time interaction was present, with an improved rate of return to an asymptomatic state in the aerobic exercise group compared with the control group. Secondary outcomes were pre-post differences in improved cognition for those in the aerobic exercise group and in improved self- and parent-reported quality of life for both groups.[22] In addition, the aerobic exercise group displayed greater *global efficiency* (a measure of integrative neural connectivity using diffusion tensor imaging), which directly correlated with reported concussion symptoms.[24] The connection between these clinical and neuroimaging results suggests a potential neurophysiological change resulting from aerobic exercise in individuals with persistent concussion symptoms. However, neuroimaging is rarely used in postconcussion aerobic exercise intervention studies, making it difficult to specifically discern the connection between the intervention and neurophysiological changes. Furthermore, neuroimaging to measure neurophysiological functioning is not easily accessible, monetarily feasible, or clinically applicable for all ATs (SOR: A).

Among adolescents with persistent concussion symptoms (ie, symptoms 3–6 weeks postconcussion), self-reported concussion symptoms improved more rapidly in the aerobic exercise group than in the stretching group.[21] Participants started daily activity at 5 to 10 minutes and worked toward a goal of 60 minutes per day.[21] These findings indicate that aerobic exercise protocols can be individually modified and used in populations not yet ready for participation in high-intensity or long-duration physical activity postconcussion. Moreover, these results provide ATs with evidence to support the use of aerobic exercise in patients with persistent symptoms after concussion (SOR: A).

Evidence[39,40] also suggests that acute and chronic aerobic exercise is positively associated with cognitive function across the lifespan. Larson-Dupuis et al[25] explored a 12-week aerobic exercise intervention aimed at identifying if aerobic exercise improved cognitive performance in participants with a concussion history. Specifically, individuals engaged in either aerobic exercise on a cycle ergometer or whole-body stretching and relaxation (control) for 20 to 40 minutes 3 times weekly. Cardiovascular fitness (ie, $\dot{V}O_2$max) improved for participants in the exercise group compared with those in the stretching control group. However, cognitive performance did not differ. Of note, the participants were sedentary, healthy asymptomatic individuals aged 50 to 70 years with a concussion history.[25] As such, the improved cardiovascular fitness may have reflected the increased physical activity compared with preintervention levels. Overall, this study provided evidence that aerobic exercise alone may not produce enough cognitive improvement postconcussion and that combining aerobic exercise and cognitive training in a more comprehensive rehabilitation approach aimed at mediating both physical and cognitive deficits postconcussion might be beneficial. To elaborate on these implications, we will discuss cognitive training–based interventions and link the findings from both aerobic exercise– and cognitive training–based interventions with the goal of improving concussion outcomes (SOR: B).

COGNITIVE TRAINING-BASED CONCUSSION REHABILITATION

Postconcussion neurophysiological changes, specifically within the ANS, affect both cardiovascular functioning[2–4] and higher cognitive processing,[5,6] each of which is impaired postconcussion and may result in symptoms.[1–4] As described in the previous sections, areas of intervention, particularly those focused on cognitive training, may supplement the effects of aerobic exercise. In this section, we address current cognitive training–based concussion rehabilitation, which has been evaluated primarily in military populations and minimally in athletic and general populations. Additionally, we suggest potential future implications of connecting the findings to current clinical practice and neurophysiological (ie, ANS) restoration. A summary of the cognitive training–based studies is in Table 2.

Most cognitive-based rehabilitation studies involved military populations versus athletic populations. In the 10-week intervention of Storzbach et al,[26] veterans with a concussion history were randomized into either a cognitive training or usual care group. The cognitive training group completed weekly 120-minute group sessions that consisted of presentations, discussions, and practical interactive exercises focused on managing concussion symptoms, memory, attention, goal setting, problem solving, and cognitive flexibility.[26] After the intervention, those in the cognitive training group reported fewer cognitive and memory difficulties and showed higher cognitive functioning than those in the usual care group.[26] Furthermore, those in the cognitive group improved on neurocognitive tests of attention, learning, and executive functioning[26] (SOR: A).

O'Connor et al[27] incorporated a cognitive rehabilitation protocol (meeting 1-on-1 with a cognitive rehabilitation specialist in which the participant was taught strategies to manage cognitive difficulties in the workplace and skills to recognize and control unhelpful behaviors at work and build positive relationships with coworkers) into usual vocational rehabilitation care for veterans. Employment rates and overall intervention satisfaction in those randomized to the cognitive training and vocational training group increased, supplying initial evidence that further investigation of this protocol on a larger scale is warranted (SOR: A).

A cognitive training intervention focusing on goal-oriented attentional self-regulation training in veterans with a concussion history and posttraumatic stress disorder (PTSD) diagnosis led to improvements in attention and executive

Table 2. Cognitive Training–Based Concussion Rehabilitation Studies

Title	Authors	Year	Cognitive Training Intervention	Key Clinical Findings
"Compensatory Cognitive Training for Operation Enduring Freedom/ Operation Iraqi Freedom/ Operation New Dawn Veterans With Mild Traumatic Brain Injury"	Storzbach et al[26]	2017	Weekly 120-min group sessions with presentations, discussions, and practical interactive exercises focused on managing concussion symptoms, memory, attention, goal setting, problem solving, and cognitive flexibility for 10 wk	Participants in cognitive training group reported ↓ cognitive and memory difficulties and showed ↑ use of higher cognitive functioning vs usual care group; cognitive group improved on neurocognitive tests of attention, learning, and executive functioning.
"Enhanced Vocational Rehabilitation for Veterans With Mild Traumatic Brain Injury and Mental Illness: Pilot Study"	O'Connor et al[27]	2016	12 Sessions with cognitive rehabilitation specialist who taught strategies to help manage cognitive difficulties in the workplace and skills to recognize and control unhelpful behaviors at work and build positive relationships with coworkers	↑ Employment rates and intervention satisfaction for cognitive training group.
"Goal-Oriented Attention Self-Regulation Training Improves Executive Functioning in Veterans With Post-Traumatic Stress Disorder and Mild Traumatic Brain Injury"	Novakovic-Agopian et al[40]	2021	Goal-oriented attentional self-regulation training (10 2-h group and 3 1-h at-home individual sessions consisting of exercises focused on improving attention regulation and how to use those skills to execute self-selected complex goals)	Cognitive training-associated improvements in attention, executive function, posttraumatic stress disorder symptoms, learning, memory, and mood disturbance.
"A Randomized Clinical Trial of Plasticity-Based Cognitive Training in Mild Traumatic Brain Injury"	Mahncke et al[41]	2021	Hour-long training sessions 5 d/wk for 13 wk completing BrainHQ (cognitive training program with 23 exercises focusing on postconcussion cognitive functioning)	Cognitive training group showed ↑ overall cognitive function at both posttraining and 3-mo follow-up visits vs control group; both groups saw improvements in depressive and cognitive symptoms.
"Cognitive Symptom Management and Rehabilitation Therapy (CogSMART) for Veterans With Traumatic Brain Injury: Pilot Randomized Controlled Trial"	Twamley et al[28]	2014	CogSMART: 12 wk of cognitive training for 1 h/wk aimed at improving positive habit learning and compensatory strategies in prospective memory, attention, learning, memory, and executive functioning	Those who completed cognitive training program saw ↓ postconcussion symptoms and ↑ prospective memory.
"CogSMART Compensatory Cognitive Training for Traumatic Brain Injury: Effects Over 1 Year"	Twamley et al[29]	2015	CogSMART	CogSMART-associated ↓ in postconcussion symptoms and ↑ prospective memory and quality of life.
"Psychiatric Comorbidity Effects on Compensatory Cognitive Training Outcomes for Veterans With Traumatic Brain Injuries"	Walter et al[30]	2015	CogSMART	Veterans who participated in CogSMART reported ↓ concussion symptoms, regardless of baseline mental health symptoms.
"Mental Health Does Not Moderate Compensatory Cognitive Training Efficacy for Veterans With a History of Mild Traumatic Brain Injury"	Pagulayan et al[31]	2017	CogSMART	Baseline mental health symptoms did not moderate CogSMART-associated cognitive improvements.
"Online Problem Solving for Adolescent Brain Injury: A Randomized Trial of 2 Approaches"	Wade et al[42]	2018	Online modules providing training for stress management, problem solving, self-regulation, communication, and social skills	Those in cognitive training group saw improved executive function and externalizing behaviors in those from less-advantaged households.
"Cognitive and Vocational Rehabilitation After Mild-to-Moderate Traumatic Brain Injury: A Randomised Controlled Trial"	Fure et al[43]	2021	Weekly sessions for 10 wk with clinical psychologists and physicians who taught strategies aimed at alleviating cognitive concussion symptoms	↑ Proportion of participants in intervention group had returned to stable employment at 3 mo; no group differences at 6- and 12-mo follow-ups.

function, neuropsychological performance composite, and mood disturbance.[41] The intervention included ten 2-hour group and three 1-hour at-home individual sessions consisting of cognitive training focusing on improving attention regulation and how to use those skills to execute self-selected complex goals. Those in the cognitive training group also reported decreased PTSD symptoms and increases in learning and memory[41] (SOR: A).

Among veterans with a concussion history and current cognitive impairment, Mahncke et al[42] conducted a multisite, prospective, parallel-arm, randomized, active controlled, double-blinded trial to assess the effectiveness of a computerized plasticity-based cognitive training program. Participants were randomized into either an experimental cognitive training program or active control group. Both groups completed hour-long training sessions 5 days per week for 13 weeks; the experimental group completed BrainHQ, a commercially available cognitive training program consisting of 23 exercises focusing on postconcussion cognitive functioning, and the active control group completed video games not focused on cognitive functioning.[42] The experimental cognitive training group exhibited improvement in overall cognitive function at both the posttraining and 3-month follow-up visits.[42] Furthermore, both groups experienced improvements in depressive and cognitive symptoms.[42] Overall, the data in these populations suggest that cognitive training can benefit cognition as well as other life-based outcomes (SOR: A).

Despite this previous work, a cognitive training criterion standard protocol does not exist. However, the authors[28–31] of several manuscripts described the findings of a novel cognitive training–based concussion rehabilitation program, the Cognitive Symptom Management and Rehabilitation Therapy (CogSMART) compensatory cognitive training protocol, which is a 12-week cognitive training intervention aimed at improving positive habit learning and compensatory strategies in prospective memory, attention, learning, memory, and executive functioning. In the initial pilot study,[28] veterans assigned to CogSMART saw reduced postconcussion symptoms and better prospective memory functioning (SOR: B). A 1-year longitudinal investigation[29] of veterans who participated in either a CogSMART protocol in addition to weekly employment support visits versus those who participated in employment support visits alone revealed CogSMART-associated reductions in postconcussion symptoms, improvements in prospective memory, and enhanced quality of life. Also, veterans who engaged in CogSMART observed improved concussion symptoms regardless of their baseline mental health symptoms[30]; baseline mental health symptoms did not moderate CogSMART-associated cognitive improvements[31] (SOR: A). Thus, better postconcussion outcomes occurred because of participation in CogSMART. Furthermore, these improvements were independent of baseline mental health symptoms. However, as veterans with mild to moderate traumatic brain injuries were included, future researchers should determine how the protocol differs in veterans with mild versus moderate injuries.

Unfortunately, limited data exist on cognitive training interventions in athletic and general populations. Wade et al[43] assessed how online modules providing training for stress management, problem solving, self-regulation, communication, and social skills would affect adolescent executive function and behavior after mild to severe brain injury. The online platform improved executive function and externalizing behaviors in those from less-advantaged households.[43] This randomized controlled trial involved adolescents with mild to severe brain injuries; therefore, the results do not directly translate to concussion-specific rehabilitation (SOR: A).

Fure et al[44] identified adults who sustained a mild or moderate traumatic brain injury 8 to 12 weeks earlier and randomized them to complete 10 weeks of compensatory cognitive training combined with supported employment or treatment as usual. Those in the intervention group attended weekly sessions with a clinical psychologist and physicians who taught strategies aimed at alleviating cognitive concussion symptoms.[44] Overall, a higher proportion of the intervention group had returned to stable employment at 3 months; however, no group differences appeared at the 6- and 12-month follow-ups.[44] Despite the intervention description of a focus on cognitive concussion symptoms, no commonly used concussion-specific clinical or research outcomes were described (SOR: B).

Overall, authors who explored cognitive training postconcussion mainly engaged military populations rather than athletic or general populations. In both military and athletic populations, authors using an online version of cognitive training produced positive results, highlighting a potentially effective intervention that could improve postconcussion outcomes and be easily accessible to individuals. More robust types of cognitive training modalities were used in military research, and additional work is necessary to characterize how ATs could use these interventions for athletes with concussion. Furthermore, we recognize that military personnel and athletes may experience concussions through various injury mechanisms that might influence the types of symptoms they report, coincide with different mental health–related impairments (posttraumatic stress, anxiety, athlete burnout, etc), and affect cognitive functioning in different ways. As such, future examination is needed to understand the effect of military- and athlete-specific cognitive training techniques.

CLINICAL RECOMMENDATION: AEROBIC EXERCISE AND COGNITIVE TRAINING INTEGRATION

Current investigators have suggested that engaging in aerobic exercise postconcussion leads to decreased concussion symptom provocation compared with usual care and that cognitive training, in various forms, enhances cognitive functioning after concussion. However, these rehabilitation modalities have only been researched independently. Integrating aerobic exercise and cognitive training postconcussion could further improve injury outcomes compared with using 1 modality. Also, integrating these rehabilitation modalities may decrease the burden on the athlete and AT by incorporating both into 1 clinical session. Specifically, providing ATs with a single integrated protocol would improve ease of administration and decrease the amount of time needed in the clinic, allowing athletes and ATs more time for additional necessary rehabilitation. This would be especially effective at the high school and collegiate levels, where student-athletes' time is divided between school and athletics, leaving them with limited

Table 3. Aerobic Exercise and Cognitive Training Recommendations Based on the Current Literature[a]

Aerobic Exercise
• Individualized, intensity-specific aerobic exercise prescription based on postconcussion baseline exercise tolerance assessment.
◦ Individualized intensity at 80% of heart rate achieved at a baseline exercise tolerance assessment (see Buffalo Concussion Treadmill Test instructions in text).
◦ Use of a heart rate monitor to identify 80% intensity.
• Mode of exercise may vary (eg, outdoor activity, stationary bike, treadmill) if heart rate threshold is met.
◦ Mode may be chosen to best suit the athlete and what he or she is most comfortable with based on his or her sport and training experience.
• Minimum 100 min of exercise completed per week with a goal of >160 min.
◦ Total amount to be divided into the number of days per week training (ie, 20–40 min, 5 d/wk).
• Continual monitoring of concussion symptoms throughout the rehabilitation process.
Cognitive Training
• Comprehensive cognitive training protocol aimed at improving prospective memory, attention, learning, memory, and executive functioning.
• Strategies focused on stress management, problem solving, self-regulation, communication, and social skills.
• Cognitive training exercises completed 1–5 times/wk.
◦ Training days can be individualized to the athlete's schedule for aerobic exercise rehabilitation.
• Administered via online platform.
• Continual monitoring of concussion symptoms throughout the rehabilitation process.

[a] The evidence-based clinical recommendations for integrating aerobic exercise and cognitive training postconcussion consist of the outlined parameters conducted within a single rehabilitation paradigm.

time to complete their rehabilitation, and ATs may be responsible for a large number of athletes and teams.

Acute and chronic aerobic exercise has been positively associated with cognitive function across the lifespan.[39,40] Yet a study of older adults with mild cognitive impairment and dementia showed that combining physical exercise and cognitive training further improved global cognitive function, activities of daily living, and mood.[45] Because concussion results in both physical and cognitive disturbances, postconcussion rehabilitation could benefit from this integrated approach (Table 3).

As reviewed earlier, Larson-Dupuis et al[25] found that aerobic exercise alone might not lead to sufficient cognitive improvement postconcussion and that combining aerobic exercise and cognitive training could offer a more comprehensive rehabilitation approach.[25] Although no current investigators have specifically integrated aerobic exercise and cognitive training, Dobney et al[15] evaluated the feasibility of a comprehensive active rehabilitation protocol in which adolescents were randomized to either early (beginning 2 weeks postconcussion), comprehensive active rehabilitation or usual care (engaging in aerobic exercise at 4 weeks postconcussion). The active rehabilitation protocol consisted of aerobic exercise (7 days per week, 15 minutes, at an intensity of 60% of the age-predicted maximum heart rate [200 − age]); coordination and skill practice (10 minutes, individualized for sport preference); visualization (5–10 minutes, individualized for sport preference), and education (information about recovery, coping with symptoms, and returning to school or sport).[15] The intervention was acceptable to physicians (ie, they would be willing to prescribe the intervention for rehabilitation) and was safe (participants could perform the active rehabilitation with minimal symptom exacerbation, as only 2 adverse events were reported). Adherence (mean days per week completed was 3.7, with intensity and duration meeting or exceeding the prescribed amounts) to and efficacy (faster symptom resolution in the active rehabilitation group than the usual care group) of the intervention protocol were demonstrated. Overall, postconcussion symptoms improved over time for both groups[15] (SOR: A). These authors provided evidence that clinical implementation of a comprehensive, combined aerobic exercise and cognitive training intervention may be useful for both athletes and ATs. However, further research is needed to understand the effect of a combined aerobic exercise and cognitive training program versus aerobic exercise or cognitive training alone.

Along with its clinical utility, integrated aerobic exercise and cognitive training may improve clinical and neurophysiological (specifically ANS) postconcussion impairments beyond each modality alone. Postconcussion neurophysiological disturbance (ie, ANS dysfunction)[1–4] affects both cardiovascular functioning[2–4] and higher cognitive processing.[5,6] Restoration of the ANS is imperative to achieve a full clinical and neurophysiological recovery, which is necessary for athletes to return to preinjury levels of play and minimize the risk of future concussions and musculoskeletal injuries.[46] Therefore, future investigators should measure ANS function to determine an intervention's clinical effectiveness and potential to support full recovery postconcussion. Additionally, this evidence should be collected via clinically relevant tools, such as wearable heart rate variability technology, to enhance clinical translation and athlete and AT usability. Authors should examine (1) the utility and effectiveness of an integrated intervention combining aerobic exercise and cognitive training postconcussion, (2) the effect of various exercise prescriptions (ie, specific intensities and dosages) on concussion outcomes, and (3) the use of neurophysiological functioning measures to determine clinical effectiveness.

CONCLUSIONS

Researchers have supplied initial support for the use of aerobic exercise, with appropriate load, to improve postconcussion symptom expression and recovery time and have indicated that cognitive training benefitted cognitive functioning after concussion. Both aerobic exercise and cognitive training are theorized to improve postconcussion ANS dysfunction; however, few authors have used outcomes that identify the effect of these interventions on the ANS. Based on the current evidence and due to the multifaceted nature of a concussion, we believe that integrating aerobic exercise and cognitive training postconcussion may improve an athlete's injury outcomes, specifically postconcussion neurophysiological and ANS function outcomes, and decrease the burden on the athlete and AT throughout the postconcussion rehabilitation period.

CONFLICT OF INTEREST

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