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CONCUSSION REHABILITATION INTERVENTIONS: A LITERATURE REVIEW OF ALTERNATIVE STRATEGIES

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ABSTRACT

Sports-related concussions (SRC) are a common injury among athletes. Despite our growing understanding of concussion pathophysiology, comprehensive rehabilitation programs remain a clinical challenge. The accepted view of SRC rehabilitation emphasizes physical and cognitive rest. However, some conflicting studies report rest may facilitate prolonged symptoms. In this review article, we report on alternative SRC rehabilitation strategies to address the complex symptom variations, including physical activity, neuro-visual training, vestibular training, music therapy, speech-language therapy, and hyperbaric oxygen chamber therapy. The mass of published works supports the utility of these alternative therapies to aid recovery, but more research is vital to clarifying these relationships. In this review, we explore the relationships between symptoms and therapies. As there is a growing body of evidence to support these alternative therapies, many questions remain when concerning the role these alternative methods play in the bigger picture of standardizing a thorough SRC rehabilitation program.

Keywords: Sports-Related Concussion, mTBI, Rehabilitation, Post-Concussive Syndrome

INTRODUCTION

Definitions

Despite the increased public scrutiny and massive healthcare burden of mild traumatic brain injuries (mTBI) in the United States, there is still much to elucidate about the many facets of this devastating injury due to its complex nature. This complexity makes it difficult to develop a comprehensive clinical definition and understand the whole pathophysiology of a mTBI. The Centers for Disease Control (CDC) defines a traumatic brain injury (TBI) as a disruption in the normal function of the brain that a bump, blow can cause, or jolt to the head, a blast injury, or a penetrating head injury. The criteria recommended to classify the injury severity of a TBI consists of structural imaging, duration of loss

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of consciousness, post-traumatic amnesia, Glasgow Coma Scale score, and the Abbreviated Injury Scale score: Head.[1,2] These criteria help practitioners classify a TBI into a mild TBI (mTBI), moderate TBI (MTBI), and severe TBI (STBI).[1,2] A mTBI is classified based on the less severe spectrum of TBI.[1–3]

The American Medical Society for Sports Medicine defines a concussion as a traumatically induced transient disturbance of brain function that involves a complex pathophysiologic process.[3] All concussions are recognized as a mTBI, but not all mTBIs are recognized as a concussion.[4,5] Although, more recently, the terms concussion and mTBI are being used interchangeably, with a call from some to eliminate the term concussion, only referring to the etiology as a mTBI.[4,5]

A systematic review by McCrory et al. published in the British Journal of Sports Medicine screened 1601 articles with inclusion criteria resulting in 36 studies concluded that a sports-related concussion (SRC) is a traumatic brain injury that is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces with several common features that help define its nature.[6] These commonalities include (1) a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head, (2) rapid onset of short-lived impairment of neurologic function that resolves spontaneously; however, signs and symptoms sometimes evolve over minutes to hours, (3) neuropathologic changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury; no abnormality is visible on standard structural neuroimaging studies, (4) a range of clinical signs and symptoms that may involve loss of consciousness; resolution of the clinical and cognitive features typically follows a sequential course; however, in some cases, symptoms may be prolonged, and (5) the clinical signs and symptoms cannot be explained by substance use, other injuries, or other comorbidities.[6]

Epidemiology

Historically, the incidence of sports-related concussions is difficult to accurately report due to the lack of a universally accepted definition as well as standardized diagnostic criteria used to collect and report this data.[2,7,8] The CDC reports that approximately 1.6 to 3.8 million SRCs occur every year. Bryan et al. published a report using data from emergency department visits, office visits, and a high school surveillance system, which showed an estimated 1.0 to 1.8 million SRC per year between the ages of 0 to 18 years and further highlighted a subset of approximately 400,000 SRCs in high school athletes.[9] Both datasets are likely under representations of the true SRC incidence as many individuals who incur an SRC do not seek out medical care.[10]

The overall incidence of SRC in children younger than 18 years of age across 12 sports was reported as 0.23 per 1,000 athletic exposures (AEs), whereas the incidence in collegiate athletes across divisions 1, 2, and 3 was reported as 0.43 per 1,000 AEs.[11] The definition of sports-related concussions varies across each professional sports league, making it difficult to quantify the overall incidence for professional athletics. Although reports of SRC incidence from the National Football League, National Hockey League, and Australian Rugby League have been estimated to be 6.61 per 1,000 AEs between 2012–2015, 3.15 per 1,000 player hours between 2006–2012, and 11.9 per 1,000 player hours between 2010–2017 respectively.[11] It is noted that more recent reports demonstrate an increasing SRC incidence that is likely due to the increased public and player awareness of the prolonged deleterious effects of untreated concussions, which has subsequently led to wider inclusion and improved diagnostic criteria.[2,11,12]

Pathophysiology Overview

Despite the significant developments in our understanding of concussion pathophysiology over the past decade, there is still more to uncover. Pathophysiology includes a combination of metabolic, physiological, and microstructural injuries to the brain.[13,14] The limitations of these studies investigating concussion pathophysiology have

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focused on the acute injury setting, primarily in animal models. That said, several disrupted physiologies after a concussion have been reported. These include dysregulation in ionic flux and glutamate release, energy crisis, cytoskeletal damage, axonal dysfunction, altered neurotransmission, neuroinflammation, blood-brain barrier dysfunction, and cell death.[15–18] The correlation between these animal studies and human pathophysiology and the relationship to clinical symptoms, remains unclear.[19] The in-depth analysis of each of these pathophysiology mechanisms is outside the scope of this paper.

Symptomology

The signs and symptoms of an SRC are multivariable and nonspecific, making appropriate diagnosis, management, and rehabilitation a unique clinical problem.[20] Many publications have categorized the most common concussion symptoms into four areas such as (1) Affective/emotional (e.g. anxiety, depression, irritability, etc.), (2) Cognitive (e.g. confusion, memory, attention, feeling in a fog/slowed down, etc.), (3) Sleep (e.g. decreased sleep, drowsiness, etc.), and (4) Somatic/physical (e.g. blurred vision, poor balance, headache, oculomotor deficits, light sensitivity, etc.).[20–23] Multiple studies have shown that symptom severity after the initial injury is one of the strongest indicators of a longer recovery.[22–25] It is warranted that more rapidly identified concussion-induced symptoms and diagnostics facilitate the recovery duration of these patients.

SPORTS-RELATED CONCUSSION TREATMENT OVERVIEW

Given the complex pathophysiology of SRC and the potential multifaceted symptom presentation of SRC patients, it is reasonable to state that rehabilitation efforts must also be facilitated in a comprehensive, multidisciplinary approach. The remainder of this report will evaluate traditional SRC rehab approaches, such as physical and cognitive rest, to alternative rehabilitation strategies, such as neuro-visual training, music therapy, hyperbaric oxygen chamber therapy, etc.

Physical & Cognitive Rest

Cognitive rest has ultimately been the prescribed regimen for post-SRC recovery. Cognitive rest can be divided into strict rest or relative rest. Strict rest recommends no performance in academics, sports, or use of technological devices. In contrast, relative rest allows those with an SRC to participate in academics or use devices if they do not exacerbate symptoms.[26–28] Previously, strict rest has been the main treatment for an SRC. However, as literature on SRC treatment has progressed, it has been suggested that acute relative rest for up to 48 hours following an SRC may be beneficial.[6] Several studies suggest that cognitive rest is crucial for the acute phase of SRC treatment, but rest persisting longer than the acute phase can prolong.[29–32] Cognitive rest lasting longer than the acute phase has the potential to exacerbate symptoms and cause more symptoms, specifically depression resulting from the removal from normal activities.[26,31,32]

A few reasons for prescribing rest following an SRC have been suggested. At the cellular level, an SRC disrupts ion potentials across neuronal cell membranes.[33] This forces the Na^+/K^+ ATP-dependent pump to function at maximal levels, depleting the body's ATP supply.[15,16,19] Cognitive rest provides a decrease in the body's energy demand, which allows the brain to recover during neurometabolic restoration by conserving the limited supply of ATP.[29,34] Other suggested reasons for prescribing rest post-SRC have been to mitigate the risk of experiencing a recurrent concussion and ease symptoms following an SRC, which helps to resolve the discomfort.[29]

Physical Activity

Although rest has been the primary form of prescribed therapy following an SRC, there has been increasing literature on the benefits of aerobic exercise to decrease the recovery time for those who have suffered an SRC. As mentioned previously,

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studies agree that aerobic exercise immediately following an SRC can be dangerous and put the athlete at risk of suffering an injury, another concussion, or exacerbating symptoms, leading to a longer recovery time. However, studies have shown that prescribed aerobic exercise following the acute stage of an SRC, especially for those with symptoms persisting well past the acute stage, can help to improve symptoms and decrease recovery time.[26,27,35,36] Although the optimal time to begin exercise treatment following an SRC has yet to be determined, a few studies have found that initiating aerobic exercise within one week of an SRC sped up recovery time, was safe for adolescents experiencing symptoms, and reduced the risk of developing persistent post-concussive symptoms.[27,37]

The preferred and recommended aerobic exercise for those recovering from an SRC has been mild to moderate intensity at a sub-symptom threshold.[26,27,35–37] One test implemented in many studies and used as a form of assessment to find a target HR for exercise treatment without exacerbating symptoms is the Buffalo Concussion Treadmill Test (BCTT).[35,36,38] This test consists of gradually increasing the intensity by increasing the treadmill's incline.[36] One test by Leddy et al. utilized an altered version of the BCTT by using a stationary bike instead of a treadmill and increasing intensity by increasing the bike's resistance, demonstrating similar results.[36] Clark et al. evaluated the utility of a transient exertion-related carotid (TERC) murmur during symptom-limited exercise to manage SRC.[39] They demonstrated that the TERC murmur was heard at a heart rate of around 150 beats per minute, while in a SRC patient, the TERC murmur was heard at around 120 beats per minute.[39]

The body experiences different consequences of a concussion. These include exercise intolerance, reduced cerebral blood flow (CBF), and interruptions in the autonomic nervous system (ANS).[13,19,36] Studies have shown that mild to moderate sub-symptom threshold exercise following an SRC can help to regulate the ANS, increase CBF, and improve exercise tolerance, resulting in a faster recovery and RTP.[27,36–40]

Neuro-Visual Training and Oculomotor Interventions

The American Optometric Association states that the most common visual symptoms induced by a concussion include photophobia/photosensitivity, poor eye tracking ability, difficulties with shifting gaze, convergence insufficiencies, reduced focusing/accommodation, loss of binocular vision or abnormal eye alignment, inability to maintain visual contact or poor eye discipline, and more. Several studies have reported prolonged visual symptoms in PCS.[34,36,41] It has been hypothesized that with the heavy burden of the visual sensory system, some other common persistent symptoms, such as headache and dizziness, may result from mismatched perceptions between central and peripheral visual processing, highlighting potential oculomotor and neuro-visual dysfunction.[42]

Standard vision training therapy conducted by an optometrist is usually indicated for strabismus, phorias, and binocular vision deficiencies, and more often, it uses established oculomotor methods.[43,44] These exercises strengthen the ability of the eyes to move with accuracy and control, resulting in better fixation, saccades, and pursuit of eye movements.[45,46] Although not commonly found or defined within the scientific literature, here neuro-visual deficits are defined as abnormalities or defects along the eye-brain axis, including the cell layers of the retinal, the optic nerve, the lateral geniculate nucleus of the thalamus, the superior colliculus and pretectum of the midbrain, the suprachiasmatic nucleus of the hypothalamus, and the visual cortical areas of the occipital lobe as well as the cognitive processing associated with visual sensory information processing. These are differentiated not to diminish standard oculomotor vision therapy but to separate the cognitive enhancements in neuro-visual training (NVT) from traditional vision training.

NVT philosophy has been proposed to follow three central themes known as the three pillars of NVT: eye discipline, oculomotor, and brain processing.[47] An overview of NVT methods includes a mixture of established oculomotor training such

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as Brock string, saccadic exercises, eye patching, etc., with peripheral vision training, eye-hand coordination drills, both monocular and binocular exercises enhanced with cognitive exercises that aim to make participants multitask and make multiple decisions quickly engage in sequential processing, spatial reasoning, and other visual-centric cognitive functions.[48–52] These reported NVT strategies emphasize the cognitive overlay of oculomotor training to improve the brain's ability to process the vast amount of visual information taken in through the eyes. Once the visual information has been processed, NVT also facilitates the decision-making process and physical action in a time-sensitive manner, which is crucial in sports.[48–52]

The University of Cincinnati Division of Sports Medicine uses NVT strategies prominently for SRC rehabilitation, among other tools.[48–52] Their use of NVT methods for SRC rehabilitation is individualized to the injured athlete, based on their own objective sports concussion baseline data that includes neuro-functional measures and the athlete's symptom reports. Their NVT rehabilitation strategies have been reported in the literature to reduce recovery times in division-1 collegiate football players with an SRC and correlated with reduced incidence of SRC.[49,50,53] Although more research into these rehab strategies and their proposed effects is necessary, there is a growing body of literature to support appropriate NVT methods for SRC rehabilitation, many of which are validated.[48-50,54,55]

Vestibular Rehabilitation

The majority of TBI symptoms typically resolve within 7–10 days, but vestibular components such as dizziness, vertigo, and balance dysfunction remain in 10–30% of cases and cause significant morbidity.[56] Vestibular rehabilitation therapy (VRT) is a physical therapy method that stabilizes one's gaze and gait after vestibular injury. VRT exercises consist mostly of head, neck, and eye movements to enhance posture and gaze stability, improve symptoms of vertigo, and improve daily life activities.[56] Foundational exercises of VRT include head-eye movements with varying body positions and activities, maintaining balance given a reduced support base while carrying out upper extremity activities, provoking vertigo, and exposing subjects to varying sensory and motor environments.[57] The two central therapeutic mechanisms of VRT involve vestibular substitution and adaptation. Vestibular adaptation concerns the readjustment of the vestibulo-ocular reflex (VOR), while vestibular substitution uses other sensory cues, like visual and sensory, to substitute for ones lost from the vestibular system.[58]

Gaze instability results from the VOR's inability to maintain gaze during head movement, and as little as 2–4 degrees per second of retinal slip is sufficient to reduce visual acuity.[59,60] The most effective stimulus for increasing the response of the VOR is the retinal slip error signal itself.[61] Inducing retinal slip is achieved by vertical or horizontal head movements while maintaining visual fixation on an object. Methods to improve the effectiveness of vestibular adaptation include slowly inducing progressively larger retinal slip errors over time as opposed to large sudden retinal slips.[62,63] Similarly, large ranges of head movement frequencies should also be applied, as adaptive changes to the VOR response are larger when there is a gradual increase in the error signal.[62,63] Diversified head movements should also be applied as the added otolithic input provides additional training effects.[64] While vestibular adaptation has proven the most beneficial form of VRT, methods of vestibular substitution, including modification of saccadic eye movements, central preprogramming of eye movements and postural responses, potentiation of the cervico-ocular reflex, and substitution of other sensory inputs such as visual and sensory for lost vestibular inputs.[61,65–67]

A meta-analysis was completed on 10 studies; only 4 used VRT as a single intervention for mTBI. Participants analyzed were of a wide age range (8–73 years). Nine of the studies reported improvement in outcomes, but only 1 study was found to demonstrate increased medical clearance for return to play within 8 weeks.[68]

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Music Therapy

Music is an integral part of the human experience, but it is often overlooked for its healing potential for TBI. With the help of trained professionals, active and receptive methods of neurological music therapy (NMT) have successfully improved TBI deficiencies.[69,70] Methods vary from study to study, as music therapy can and must be tailored to the patient(s) for optimal results. Active methods included gait training, instrument learning, instrument playing, songwriting, and singing/vocalization. Receptive methods included listening to music, sometimes with supplementary imagery.[69] Depending on the study and patients' needs, these methods may be combined and delivered in individual or group settings to address somatic, cognitive, and emotional complaints.[71]

With the potential to tailor the experience, there are many areas that music can benefit that other TBI rehabilitation strategies cannot manage. One of these is gait, where rhythmic auditory stimulation with gait training leads to higher functional gait assessment scores in patients post-treatment, with half improving enough to be no longer considered a fall risk.[72] Another area under study is the combination of TBI and post-traumatic stress disorder (PTSD) often seen in the military.[70,73] Amongst service members, music therapy helped with both TBI and PTSD, with the majority of anecdotes regarding the treatment as also helping with mood, emotion, depression, anxiety, and general quality of life.[70,73] These results are likely tied to the neuroplastic effects of music therapy, with proven treatments such as learning piano causing neuroplasticity and changes in orbitofrontal networks.[70,74,75] In congruence with the neuroplastic effects, NMT is also shown to reduce brain network dysfunction, making it one of the few proven TBI rehabilitation methods for brain network dysfunction.[74] The last and most underrated quality that sets music therapy apart is enjoyment. Music activates areas in the brain associated with reward, motivation, emotions, and arousal.[76] This is echoed by the patient post-treatment response of enjoying NMT.[70–72]

Present results for music therapy are promising, but there are limitations to its application. One limiting result is that treatments provide improvement but do not entirely eliminate deficiencies.[72] This is why NMT is great for TBI and should be included in concussion recovery but is most beneficial to the patient when used in tandem with other TBI rehabilitation strategies.[73–75] Another limitation is the quality of available publications. In the past twenty years, the number of music therapy publications has quadrupled, with an average of 22 per year from 2000 to 2004 and an average of 87 publications per year from 2015 to 2019.[75] Unfortunately, NMT is still under scrutiny as many literature searches yield publications with small sample size, lack of controls, and other general errors that hinder credibility in practice or systematic review.[72–75] Finally, rehabilitation can be blocked entirely by needing a professional touch. Without professional intervention and supervision, music therapy is unlikely to yield improvement and, in some cases, such as TBI coupled with PTSD can reaggravate injuries or symptoms.[73] With this considered, future research aims to include larger sample sizes, control groups, and global modalities as appropriate. If available, music therapy is a beneficial addition to any TBI rehabilitation program, but with current resources, rehabilitation programs will need the expertise to utilize it properly.

Speech-Language Therapy

Speech therapy is a common practice to address TBI and usually is facilitated by a speech-language pathologist (SLP). General modalities for speech therapy include compensatory speech, cognitive therapy, cognitive processing therapy, psychoeducation, and psychotherapy.[76] Through the use of these practices, SLPs in schools have sped up the return to learning and return to play times.[76] In patients of all ages, speech therapy helped quell their persistent PCS.[76–78] For military service members, speech therapy also leads to improvement of TBI and PTSD symptoms.[79] These results show great promise for speech therapy, but in the end, will be limited by the associated SLP.

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Though speech therapy is limited to mostly use by SLPs, they are forever learners. Cognitive rehabilitation is in their scope of practice, an ever-developing field that includes functional and flexible knowledge.[80,81] Unfortunately, this leads to inconsistent beliefs on TBI patients' terms, diagnostics, and care.[82,83] The quickly evolving field is put into the hands of the individual by the Center for Disease Control and Prevention (CDC) reports that the SLPs role is to determine the type, intensity, and exposure of treatment.[80,84] Amongst these individuals, the percentage has been increasing in the past ten years, but many do not have formal concussion experience and training. However, with their commitment to learning and community improvement, developing SLPs still find ways to make influential members of a TBI rehabilitation team. SPLs are often in schools and work as counselors for students from pediatric age through college.[83-85] They are responsible for the quality of life and unique challenges of the patient and work with other professionals to assess academic, environmental, and emotional needs that arise. The SLP's variety of communication strategies and experience help them become a life advocate, coach, and planner for TBI patients. Then, the speech therapy results may also be possible with a well-educated SLP.

Hyperbaric Oxygen Chamber Therapy

Hyperbaric oxygen therapy (HBOT) is a form of medical treatment and management of certain pathologies achieved by pressurizing a closed environment above normal atmospheric pressure with pure oxygen gas.[86–88] HBOT currently has well-established foundations for the treatments of carbon monoxide poisoning, necrotizing soft-tissue infections, and air or gas emboli consistent with dive-related injuries.[86-88] The primary therapeutic mechanism of action for HBOT is the increase in O_2 partial pressure, resulting in increased O_2 saturations and intracellular generation of reactive oxygen and nitrogen species. These reactive species are known to have central roles in cell signal transduction cascades.[86–88]

A variable amount of irreversible neurological damage is sustained within the first phase of TBI during the onset of injury.[15–20] The secondary phase of TBI after the injury is primarily associated with pathologies of edema, hypoxia, and ischemia, along with other inflammatory and biochemical processes.[15–20] Acknowledging the relationship between hypoxia and neuronal cell death, HBOT was thought to be an effective treatment, as it has demonstrated beneficial effects post-TBI in animal models. Some of these effects include increased vascular density of contused hippocampi, reduced secondary cell death and reactive neuroinflammation, maintained integrity of mitochondrial membranes, and reduction in the mitochondrial apoptotic pathway.[89-92]

A meta-analysis of four studies provided 238 enrolled participants within an age range of 23–44 years.[93] Participants were placed into low and high oxygen dose groups and underwent 30–40 sessions of 60–90-minute therapies. The cognitive progress of the participants was then subjectively followed using the Rivermead post-concussion symptoms questionnaire (RPQ), PTSD Checklist (PCL), and the neurobehavioral Symptom Inventory (NSI). The analysis found that HBOT had no significant effect on post-concussive symptoms compared to the sham groups.[93] Although these 3 assessments, (RPQ, PCL, and NSI) have well-established foundations, they are still subjective performance evaluations prone to bias and confounding variables associated with self-administration. However, objective SPECT imaging was obtained in one randomized trial and showed improved cognition and elevated brain activity.[89] Future exploration of HBOT for TBI will require the implementation of large-scale cohort or observational studies to provide effective information for the design and execution of future clinical trials.

SUMMARY & RECOMMENDATIONS

Undeniably, the complexity of SRC can result in a breadth of possible symptoms, making this a unique clinical problem for prevention, diagnostics,

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and rehabilitation. These symptoms are characterized into four main groups: affective/emotional, cognitive, sleep, and somatic/physical. Treatment of the many components of acute and persistent symptoms after an SRC remains a challenge. With this multifaceted presentation, SRC patients may benefit from a multidisciplinary approach to their rehabilitation, including alternative therapies to the traditional physical and cognitive rest. Although more research is strongly recommended to develop and validate better rehab methodologies, with the variable symptoms reported after an SRC, we must stay open-minded on rehabilitation strategies that have demonstrated success for some patients. Ideally, with further investigation, these alternative therapies can be formulated into a standardized protocol for a comprehensive SRC rehabilitation program.

Limitations

One major limitation of this study is the basis of the methods used in the cited references. Given that these strategies are not standardized, there may be variations in the definitions for each therapy and differing methodologies for the same defined therapy. Furthermore, there may be other alternative therapies not included in this review. Although this report aims to provide a comprehensive review of alternative SRC rehabilitation strategies, some key studies may not have been included involuntarily. Additionally, the studies cited throughout this report contain varying levels of scientific rigor. Thus, this report can potentially be subjected to selection and publication bias.

Suggestions for Future Research

Future directions for SRC rehabilitation include more comprehensive diagnostic criteria, a deeper understanding of the pathophysiology of a concussion, the correlation between the pathophysiology and presenting symptomology, and validation of effective rehabilitation methods. All these routes are imperative in developing a better understanding of this injury and effective therapies for patients. Regarding future research directions into SRC rehabilitation, we encourage more randomized control trials with detailed method reporting for reproducibility and to aid in validation.

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CONFLICT OF INTERESTS

Jonathan Vincent declares that he consults for his family's company, Dynavision Global Holdings LLC (DBA: Dynavision International), and the founder of a Limited Liability Company, Inneuractive LLC, that trains and educates athletes, coaches, athletic trainers, and other interested healthcare practitioners in NVT methodologies for performance enhancement. The other authors declare that they do not have any conflicts of interest.

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