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joseph f. clark
University of Cincinnati, clarkjf@gmail.com

Enna Selmanovic
mount sinai, Enna.Selmanovic@mountsinai.org

Kip Drewry
University of Cincinnati, kdrewry88@gmail.com

Jon Vincent
University of Cincinnati, jvincent0295@gmail.com

Aaron Himmler
University of Cincinnati, Kuehnhav@ucmail.uc.edu

See next page for additional authors

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Authors

joseph f. clark, Enna Selmanovic, Kip Drewry, Jon Vincent, Aaron Himmler, Bob Mangine, Kim Hasselfeld, Jane Khoury, David polanski, and jon divine

Survey of Prevention and Intervention Strategies Reducing Return to Play Post-Concussion in Division 1 Football

Joseph F. Clark, PhD, ATC*, Enna Selmanovic†, Tyler K. Drewry, MD‡,
Jon C. Vincent*§, Aaron Keuhn-Himmler ATC MS†,
Robert E. Mangine, MEd, PT, ATC†, Kimberly A. Hasselfeld, MS§,
Jane C. Khoury, PhD‖, David Polanski, MSΔ, Jon G. Divine, MD§

* Department of Neurology and Rehabilitation Medicine, University of Cincinnati College of Medicine;
†Department of Athletics and Novacare Rehabilitation, University of Cincinnati;
‡Department of Family Medicine, University of Cincinnati College of Medicine;
§Division of Sports Medicine, Department of Orthopaedic Surgery, University of Cincinnati College of Medicine;
‖Division of Biostatistics and Epidemiology, Cincinnati Children's Hospital Medical Center;
ΔStudent-Athlete Performance Center, The University of Tulsa, Tulsa, Oklahoma

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Corresponding Author:
Joseph F. Clark, Ph.D.
Department of Neurology and Rehabilitation Medicine
University of Cincinnati
7110 MSB, ML 0536
Cincinnati OH 45267-0536
Clarkjf@gmail.com
Phone 513 558 7085

***Abstract*.**

Introduction

Sports related concussion, also considered mTBI, has remained in the public eye due to heightened fear concerning playing football and other collision-based sports. Concussion prevention, as well as rehabilitating the brain after a concussion, is a high priority for many sports medical practitioners as well as for athletes. For these reasons, researchers associated with the American Athletic Conference (AAC) have surveyed concussion incidence in football. One of the AAC teams engaged in regular neurovisual training (NVT) and concluded this training program is associated with faster return to play post-injury in this observational cohort study.

Methods

The 12 schools of the AAC were surveyed from 2014 - 2018 concerning football induced concussions.

Results

We found that the AAC's average seasonal concussion rate was m= 12.1, SD=1.02 concussions per year and the average return to play time was m=13.8, SD= 6.3 days. In the team where there was consistent NVT and NVT oriented rehabilitation post-concussion, we found that the concussion rate was m= 3.5, SD= 1.3 concussions per year and the return to play time was m= 8.6, SD= 1.5 days. Both numbers are significantly lower than in the other AAC teams.

Discussion

The current paper reports that there may be mitigation strategies that can be employed to aid in faster return to play times, as well as decrease the incidence of concussions. Such attempts to make football safer are needed as brain injury has been associated with long term consequences. Improving safety and brain health through mitigation strategies along with rehabilitation methods may aid in keeping athletes safer during play and throughout their lifespan.

Introduction

There has been growing debate amongst sports medical professionals as well as neurologic practitioners as to the best way to manage sports related concussions (SRCs) that may occur during a sporting event; also known as mild traumatic brain injury (mTBI) (Harmon et al., 2013; Kelly, 1999; McCrea et al., 2003; McCroy et al., 2013).While many rule and procedural changes have been made concerning diagnosis and pull from play following SRC, what is still hotly debated is injury prevention, injury management, and timing of return to play. A component of this debate concerns the "wait and see" method (also called brain rest) versus rehabilitation and therapy post-concussion (Asken et al., 2018; Clark et al., 2014, 2020). Several practice guidelines for mTBI and concussion continue to recommend a brief period of rest (Management of Concussion/mTBI and Working Group, 2009; Ingebrigsten et al., 2000; New South Wales Motor Accident Authority, 2008), with the Zurich Consensus guidelines going as far as describing rest as the "cornerstone of concussion management" in previous years (McCroy et al., 2009). Although sport and governing bodies such as the American Academy of Neurology, the National Athletic Association and the National Athletic Trainer's Association have begun to embrace gradual exertional protocols (American Academy of Neurology, 2020; Kelly et al., 2014; Broglio et al., 2014) many entities and physicians remain cautious when recommending mental and physical activity following sports-related concussions (Carson et al., 2014). In this report, we present further evidence to support a program based on integrated intervention for Division I college football players designed to facilitate an athlete's return to play post SRC.

The CDC estimates that >20% of head injuries in the United States are sports-related concussions and that this number has doubled in the last 10 years (Centers for Disease Control and Prevention [CDC], 1997; Trinh et al., 2020). Furthermore, the NCAA has previously reported an estimated average of 10,500 concussions per year with 3,400 of these among football players (National Collegiate Athletic Association [NCAA], 2020). To address the public health concern, rule changes and equipment improvements have been implemented to improve the overall safety of athletes. For example, hard and soft helmets have been shown to prevent impact injuries such as fractures, bleeding, and lacerations, but have not shown to reduce the incidence of concussion. Furthermore, mouth guards have been shown to help prevent oral-related trauma but again have no effect on the severity or prevention of concussion (Harmon et al. 2013, 2019). As a result of the lack of evidence in concussion management, there has also been considerable debate amongst sports medical professionals as well as neurologic practitioners as to the best way to manage SRC. In regards to mTI or concussions, rehabilitative methods in practice range from complete brain rest to gradual reintroduction of activity (Schneider et al., 2013; Silverberg & Iverson, 2013). Examples of gradual activity include light and closely monitored aerobic exercise such as the Buffalo Concussion Treadmill Test or submaximal aerobic exertion on a stationary bike (Gagnon et al., 2016; Leddy & Willer, 2013), vestibular interventions by way of proprioception training and gaze stability (Ziaks et al., 2019) and vision/ocular motor training (Barton & Ranalli, 2020; Ziaks et al., 2019). Unfortunately, there is no gold standard for timing of return to play and gradual rehabilitation post SRC (Carson et al., 2014; Schneider et al., 2013; Silverberg & Iverson, 2013). The latest consensus statement by the 5th International Conference on Concussion in Sport has recommended a brief period of rest (24-48 hours) after sustaining a concussion and then starting gradual exercise below symptom exacerbation thresholds (McCroy et al., 2017).

The graduated exercise protocol relies on being asymptomatic at pre-defined stages of rehabilitation before progressing to further levels and finally being medically cleared to play (McCroy et al., 2017). The idea of cognitive rest) has been challenged by more recent methodology of return to play involving integrated rehabilitation and therapy post-concussion (Gupta et al., 2019; Leddy & Willer, 2013; Schneider et al., 2013). The decision to return to play is an individualized clinically-based decision. For all levels of play, recognizing the signs and symptoms of a concussion accurately and rapidly is the first step to advance through a rehabilitation protocol aimed at a safe time frame for return to play (McCroy et al., 2017).

Multiple concussion studies have cited that the majority of concussion cases have resolution of symptoms by about 10 days (Collins et al., 2006; Guskiewicz et al., 2000; Lovell et al., 2006; Makdissi et al., 2013; McCrea et al., 2003; McCroy et al., 2013). Cognitive impairment seems worst at the initial time of injury then gradually lessens by day 5, with symptomology of 60.1% of all concussions resolving by day 7 (McCrea et al., 2003; Wasserman et al., 2016). Despite the majority of concussions resolving within a short period of time, approximately 10% of concussed athletes will experience persistent symptoms past 1 week and up to 3 months after initial diagnosis (McCrea et al., 2003, 2013).

A review of current literature suggests that an optimal period for rest following mTBI and concussion is unclear however management for gradual return to activity or play should be conducted in a manner that does not involve significant exacerbation of concussive symptoms (Schneider et al., 2013). Additional findings also suggest that the initiation of a graduated return to play protocol can occur before an absolute absence of all symptoms with the understanding that higher initial reported symptom severity scores can be associated with longer duration of a RTP protocol (Brett et al., 2020). In review, proposed management for gradual return to activity or play by way of a step-wise, graduated rehabilitation strategy may be beneficial for those who endure an SRC and are slow to recover (Gagnon et al., 2016; McCroy et al., 2017; Schneider et al., 2013). In addition to the proposed aerobic and low-level exercise recommended for RTP, the use of vision and vestibular therapy in the form of ocular motor training has increasingly been used to treat visual complaints and related persistent symptoms following mTBI (Barton & Ranalli, 2020; Clark et al., 2014, Ziaks et al., 2019). Visual complaints and symptoms are common after head trauma and improving ocular motor function is said to reduce visual symptoms from such head trauma (Barton & Ranalli, 2020). With the emerging discipline of vision training for performance enhancement in sport, it can be hypothesized that similar improvement of both vision and processing speeds may also lend to better injury prevention (Clark et al., 2020) and potential subsequent return to play.

For the purpose of this study, we present evidence that a neurovisual oriented training (NVT) program can be associated with faster return to play post injury. This is based on a program of integrated intervention regarding Division I college football players, designed to facilitate return to play post SRC. We postulate that early rehabilitation and strengthening of deficits post-concussion provides earlier symptom resolution in concussed athletes and earlier timeframe for return to play.

Methods

The aim of this research study was to present evidence of a neurovisual oriented training (NVT program) that can be associated with faster return to play post injury. To do so, in 2016, the American Athletic Conference (AAC) completed a quality assurance type survey of athletic trainers covering football to determine risks and management parameters for the AAC teams. This voluntary survey was sent to all head football trainers requiring a retrospective review of concussion etiology, number of concussions, player specifics, protocols and RTP recorded and confirmed by sports medicine analysis and NCAA protocol submission. The initial survey covered years 2014-2016 and a second survey covered years 2017-2018. No personal identifiers were collected concerning individual athletes and their injuries. Results are reported as a cluster analysis with each team forming one cluster. This work was declared by the local IRB to be exempt from review; letter on file from IRB chair.

The survey queried the sports medical staff within the AAC institution. The results are summarized below:

List of AAC Teams: East Carolina, Houston, Memphis, Navy, SMU, Temple, Tulane, Tulsa, University of Central Florida, University of Cincinnati, University of Connecticut, University of South Florida.

The AAC survey, collected by Tulsa University (DP), asked questions concerning total number of concussions; practice concussions; game concussions, average time lost, range for time lost, medical disqualification, and concussion prevention measures such as neck strengthening, and rehab strategies. We did not standardize the definition of concussion or concussion management for the teams. Each school used their own protocols and medical management. Data are voluntarily reported and de-identified with the University of Cincinnati being the only identified team.

The protocol described below includes various components of the NVT program that are conducted at The University of Cincinnati. Pre-season brain training is conducted 4-5 times per week for 3 weeks while brain training during season occurs at least 1 time per week for 20 minutes. We continue to use an aggressive and integrated rehabilitation philosophy to encourage exercise as soon as practicable by assessing symptoms and exertion tolerance (Clark et al., 2016) allows the athlete to complete gradual cardiovascular exercise as part of their rehab post-concussion on the equipment of their choice.

Cardiovascular: Athletes are asked to choose between walking and light jogging on a treadmill or elliptical or using a stationary bicycle. Athletes begin by engaging in submaximal aerobic training (increasing heartrate to 60-80% maximal capacity) for 20 minutes. The length and intensity of this protocol was chosen as previous research provides evidence of its association with improved cognitive function in healthy athletes, its representativeness of average intensity experienced by athletes during practice and includes the target heartrate by various concussion in sport entities (McCroy et al., 2017; Moore et al., 2012; Sicard et al., 2020). After 20 minutes, athletes are then asked to identify any new or persistent symptoms and are assessed for a transient exertion-related carotid (TERC) murmur that may indicate maximal yet safe exertional tolerance and target heart rates (Clark et al., 2016, 2019). Once the athlete has been cleared & remains asymptomatic, they may return to submaximal aerobic exercise for an additional 20 minutes. If new symptoms arise or a TERC murmur is identified, the athlete is asked to terminate aerobic exercise for this session. Athletes normally complete up to 1 hour of aerobic exertion per day until cleared to return to play. Furthermore, short aerobic exercise may also be implemented directly into NVT exercises described below as a consequence of multi-tasking and sport specific exercise.

In conjunction with aerobic exercise, we also have athletes engage in integrated NVT for rehabilitation (Clark et al., 2015a, 2015b) where we do cognitive and neurosensory rehabilitation to "light up" complex pathways of cortical function (Clark et al., 2020) NVT rehabilitation includes variation of the following:

Light Board Vision Training: Dynavision D2 lightboard is an FDA cleared device used to train reaction time and executive processing. Athletes are directed to stand approximately 18 inches away from the light board while trying to reach the lights in the outer ring (Clark et al., 2015a, 2015b, 2020). The athlete may adjust their position closer or further away from the board in order to reach all of the lights and the board may be moved up and down using a power switch to ensure they are at eye-level with the screen. Dependent on the exercise, athletes use their peripheral and central vision to press flashing lights as they appear. Simultaneous executive and verbal tasks such as word finding or simple mathematics can be completed.

Brock String: A string with different colored beads is attached to a fixed object at one end and held up to the athlete's nose on the other end (Clark et al., 2015a, 2015b, 2015c, 2017, 2020). Starting with the closest colored bead, the athlete is to focus on each equidistant bead as they move along the string. By focusing or moving the beads, suppression and convergence can be improved. It is important to note that this drill may be contraindicated for people with esophoria as it tends to be a convergence drill.

Tachistoscope: Sports-related images are flashed on a screen for 0.3 seconds with numbers and/or symbols. Athletes are required to recall the numbers and/or symbols when prompted immediately after the image disappears. As the power point progresses, the length of numbers and/or symbols increases and the images may become more challenging by modifying contrast or position.

Saccadic Eye Movement Training: Athletes are placed 8 feet away and centered between 2 saccadic eyecharts (8.5 x 11 inches) also placed approximately 6-8 feet apart on a wall. The athletes are then instructed to alternate reading letters or numbers on the charts for one minute while keeping their head still and only moving their eyes. Athletes are normally asked to progress down the lines on each sheet but across the pages horizontally as they complete another line. Ensure that both charts are placed at eye level and the athlete's vision is not obstructed.

Near Far Training: Athletes are placed 10 feet away from 1 chart on a wall at eye-level and provided with a smaller one (3.5 x 2.5 inches) to be held in one hand, 4-6 inches from their nose. Similar to saccadic eye movement training, the athletes are then instructed to alternate reading letters or numbers on the charts for one minute while keeping their head still and only moving their eyes. Athletes are asked to progress down each line but across the pages horizontally as they complete another line. It is important to remind the athlete that both eyes should come into focus on the near target (smaller chart) as well as the far target when alternating.

Pitch and Catch: Athletes are instructed to stand 8-10 feet away from each other and throw various colored balls with various shapes drawn on back and forth for 2-5 minutes (Clark et al., 2015a, 2020). To increase difficulty and work on executive processing, athletes can be instructed to catch specific colored balls with specific hands (ie. red with right, green with left) and call out the shapes that have been drawn on prior to catching. Furthermore, athletes may be directed to turn away from their partner requiring them to turn and catch as the activity progresses. Lastly, athletes may also be instructed to use strobe or pinhole glasses for a pitch and catch routine as described below.

Strobe and Pinhole Glasses: Stroboscopic glasses have LED lenses that flash on and off with a prescribed and modifiable cycle minutes (Clark et al., 2015a, 2015b, 2015c, 2020). Pinhole glasses, also known as stereoscopic glasses, have a series of pinhole-sized perforations in the lens. Both types of glasses may be used to block different aspects of visual input during various drills; the rapidity of flashes on the strobe glasses or the narrowing of the visual field for the pinhole glasses can be increased to allow athletes to adapt and rely on less visual input for processing of spatial information of objects being thrown. For NVT purposes, athletes are asked to alternate using both strobe and pinhole glasses during exercises like pitch and catch with a partner or the use of 6-sided reaction ball drills against a wall or with a partner.

The above neurosensory rehab is designed to improve reaction time and peripheral vision reaction time (Clark et al., 2017). Typically, an athlete is seen in the acute phase post-concussion to manage symptoms. They are seen regularly (every other day) to be assessed for both signs and symptoms that may limit progression or subjective and objective improvement (lack of symptoms) that may allow for gradual increase in duration and intensity of cardiovascular exercise and eventually RTP.

Statistics

The outcome variable: number of lost days were examined for evidence of outliers and deviation from the assumption of normality. Secondary outcomes of concussions were collected, analyzed and reported as well. For the first 3-year data collection an analysis an interaction of year by use of the early rehabilitation program was examined. Where this was not statistically significant a main effects model including time and early rehabilitation program was used. School was used as the repeated factor in all analyses. For the full 5-year data set an analysis was performed using SAS®, version 9.4 (SAS Institute, Cary NC). A p-value of < 0.05 was considered significant (Andrade, 2019).

Results

The University of Cincinnati concussion data are compared to the total AAC concussion data obtained by the Tulsa Group Survey (note; we do not disclose responders or non-responders except to say that the University of Cincinnati did respond, and the results are presented herein). Reported here are concussions per year that occurred during organized practices or games from 2014-2018.

A total of 570 concussions were recorded from the responding schools between 2014-2018 seasons within the AAC with 344 occurring in practice.

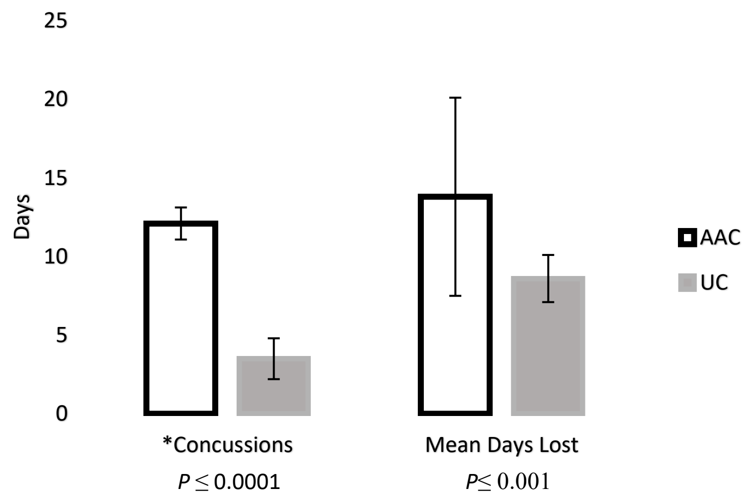

Figure 1. Comparisons of number of concussions per year comparing the AAC to the University of Cincinnati's rates. We also present the data for the average number of days missed for athletes diagnosed with a concussion comparing the AAC to the University of Cincinnati. Error bars are SD.
* concussion incidence for UC excludes 2017 for the reasons presented in the text.
UC = University of Cincinnati
AAC = American Athletic Conference

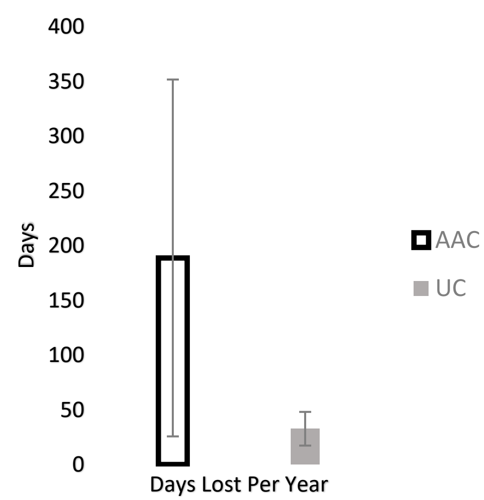

Figure 2. Aggregate number of days lost per year for the AAC compared to the University of Cincinnati. Error bars are SD.

At The University of Cincinnati, where there was integrated NVT and rehabilitation post-concussion (Clark et al., 2014, 2020), we found significant differences in the length of RTP and incidence of concussions per year between 2014-2018 compared to the rest of the AAC (Figure 1). Return to play durations for the AAC were *m*= 13.8, *SD*= 6.3 versus *m*= 8.6, *SD*= 1.5 days (*P*=0.000145). Average of total concussions for the AAC was *m*= 12.1, *SD*= 1.02 compared to The University of Cincinnati *m*= 3.5, *SD*= 1.3 is significantly different (*P*= 0.037).

In Figure 2 we report the total number of days lost for the AAC schools versus The University of Cincinnati (*m*= 188.7, *SD*= 163 to *m*= 32.7, *SD*= 15.4, *P* = 0.000001). Days lost represents the total amount of missed practices and or games the team had from all their athletes' concussions and reflects the number and duration of the absence from the sport.

Figure 3 reports a post hoc analysis, plotting the rates of concussion for The University of Cincinnati from 2014 to 2018 as well as the return to play durations. Of note, there were 10 reported concussions in 2017 when The University of Cincinnati temporarily discontinued its NVT oriented concussion prevention program. Growing empirical evidence demonstrates that NVT leads to an improved control of extra and intraocular muscles of the eyes which in turn leads to improvement in muscle memory and peripheral visual fields (Clark et al., 2020). With this in mind, it can be inferred that the incorporation of a NVT oriented concussion prevention program may lead to both performance enhancement and injury prevention (Clark et al., 2020). The rehab and return to play program was unchanged. As noted in the graph of the return to play durations, there was no increase in return to play duration.

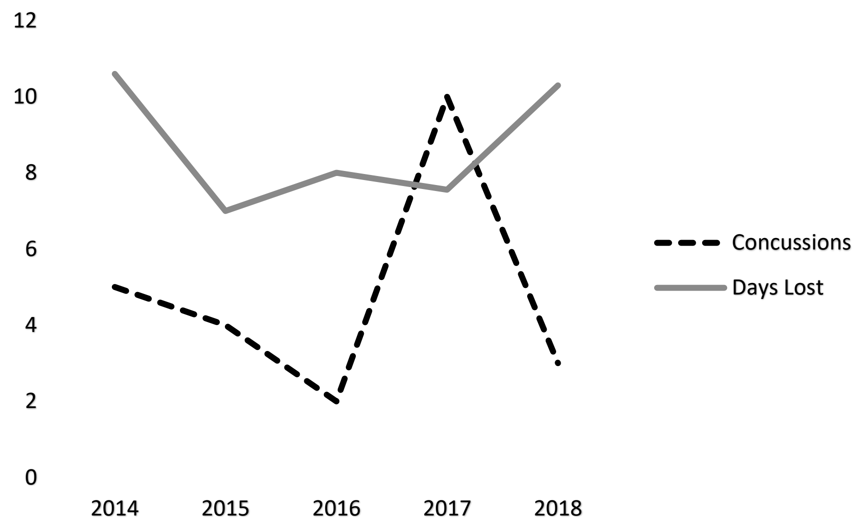

Figure 3. The University of Cincinnati incidence rate and return to play rate from 2014 to 2018. In 2017 the pre-season NVT prevention program was discontinued and there was an apparent bump up of the concussion rate. The average return to play rate remained flat during this time frame and the NVT rehab program was unchanged from 2014 to 2018. Solid line = mean days lost from concussion. Dashed line = concussions per year.

Discussion

The purpose of our study was to present evidence of an NVT program that can be associated with reducing the duration of RTP post SRC. Over five seasons (2014-2018), the University of Cincinnati football team, which underwent pre-concussion neuro-visual training (minus 2017) and post-concussion rehabilitation. There are two main discussion items that arise from this study; the first is that the University of Cincinnati concussion program may be associated with a significant decrease in RTP duration post-concussion. Along with this first item, as reported previously, The University of Cincinnati football team undergoes extensive NVT and has a significantly lower rate of concussions. In support of this assertion, we have descriptive parameters concerning concussion rates and time missed for the AAC and University of Cincinnati (Figures 1 and 2). Second, we have a post hoc analysis suggesting that the concussion prevention component of our NVT is subject to washout. In 2017 when the NVT program was suspended the concussion rate for the University of Cincinnati increased to 10 in one year (Figure 3). Below we discuss the putative ramifications of these results.

For the purposes of this paper, we characterize NVT as distinct from vision training. Neurovisual training (NVT) serves as an integrated program that combines traditional vision training methods described herein with a cognitive overlay in the form of standalone executive functioning objectives and multitasking activities dependent on the exercise (Clark et al., 2012, 2014, 2015a, 2020). Vision training is often used by Optometrists and similar eye care practitioners for treating ocular motor deficiencies (Barton & Ranalli, 2020). Vision training in isolation of brain or cognitive training is highly established and is not NVT. We use the expression NVT not to diminish the importance of vision training, but to separate our NVT program from traditional vision training.

We firmly believe that brain training prior to injury (Clark et al., 2015a) in conjunction with aggressive and integrated rehabilitation strategies (Clark et al., 2014) as presented herein work together to aid in return to play and decrease injury risk. Such cognitive rehabilitation is considered the most effective way to reduce disabling consequences of TBI including concussion, based on the principle of brain neuroplasticity (Galetto & Sacco, 2017). Furthermore, "vision therapy" has been many times considered to aid in the rehabilitation and enhancement of both visual as well as brain processing speeds (Barton & Ranalli, 2020; Clark et al., 2015a) skills necessitate processing of sensory information and coordination between the occipital lobe and the motor cortex (Clark et al., 2020). With this in mind, an argument may be made in favor of the use of NVT that incorporates the concept of "lighting up" (or activating) several complex pathways that may not only be critical to optimal athletic performance (Clark et al., 2020) but also better cognitive and visual outcomes post mTBI.

Research demonstrates that there is a variable period of impaired neuroplasticity following mTBI that may be diminished with exercise, suggesting the need to implement more aggressive and active approaches to rehabilitation (Romeu-Mejia et al., 2019). The addition of a cardiovascular component to rehabilitation post mTBI and concussion in the form of aerobic exercise has demonstrated increasing promise and benefits such as neuroplasticity, neurogenesis and improved cognitive functioning (Schneider et al., 2013; Silverberg & Iverson, 2013). This is supported by the faster return to play rates and lower injury rates for the University of Cincinnati when doing NVT.

The pre-season brain training is conducted 4-5 times per week for 3 weeks while brain training during season occurs at least 1 time per week for 20 minutes. The pre-season NVT we have used is very similar to the rehabilitation modalities used post injury (Clark et al., 2015a, 2020). When the players/patients have a familiarity with the rehab modalities, it is likely that muscle memory improves leading to quicker progression through RTP protocols and potential brain healing. If, as we suspect, the brain has been conditioned with brain training exercise, there is a "program" that the brain can use as a template to recover post injury. The implication of this thesis is that it may be feasible to initiate injury prevention strategies and use those same strategies, NVT in this case, to enhance neuroplasticity and accelerate recovery.

According to the American Medical Society of Sports Medicine (AMSSM) Position Statement, the most common sideline measurements used to aid in the diagnosis and management of concussion are the use of symptom scores such as found in a Graded Symptom Checklist (GSC) or Post-concussion symptom scale (PCSS) (sensitivity 64-89%, specificity 91-100%) (Lau et al., 2009; Lovell et al., 2003, 2004; McCrea et al., 2003; Peterson et al., 2003; Van Kampen et al., 2006), the Standardized Assessment of concussion (SAC) (sensitivity 80-94%, specificity 76-91%) (Barr & McCrea, 2001; McCrea et al., 2003; Daniel et al., 2002) and the Balance Error Scoring System (BESS) (sensitivity 34%–64%, specificity 91%) (Bell et al., 2011; McCrea et al., 2003). After administration of some of the assessment tools mentioned above, progress of an individual athlete is tracked, and this objective evidence is used to help make clinical decisions regarding appropriate time frame for RTP. We believe that the NVT described herein can be a supportive mechanism in this RTP paradigm as it provides neuro-based information (Clark et al., 2015c, 2020; Liu et al., 2020, Ziaks et al., 2019) and neuro-based rehab (Clark et al., 2014).

The novel use of NVT in prevention of concussion can help propel the research of objective measures that may standardize concussion management. Currently, medical professionals and athletic trainers rely on self-reported symptoms to monitor concussive symptoms (Maroon et al., 2000; McCroy & Berkovic, 2000; Piland et al., 2003) which in turn determines whether an athlete may be cleared to return to play. Objective methods and measurements are lacking but would provide invaluable assistance in determining RTP timing or eligibility. Some potential objective measures to help with RTP considerations and even preventing concussions include examining concussed athletes for transient related carotid (TERC) murmurs, visual sensory deficits, and balance deficits (Bigsby et al., 2014; Clark et al., 2014, 2016, 2020).

Leddy and Willer (2013) diagnosed physiologic dysfunction post-concussion by evaluating heart rates in patients subjected to graded treadmill exercise testing. In this study, concussed patients had significant symptom exacerbation at submaximal heart rates. This study supports the use of objective cardiovascular measurements to assist with return to play decision-making. Similarly, Clark et al. (2016) postulated that athletes with a concussion would have a TERC murmur heard at a lower threshold than non-concussed individuals on exercise treadmill testing. Clark et al. effectively demonstrated that TERC murmurs were auscultated at lower average heart rates in concussed athletes as compared to controls. These two studies provide objective measurements as well as invaluable insight in determining a safe level of cardiovascular exercise in rehabilitative protocols. Additionally, visual sensory symptoms (central field vision dysfunction like double or blurry vision and peripheral field dysfunction) may be useful indicators of concussion management (Bigsby et al., 2014; Clark et al., 2020; Crowe et al., 2016). Central vision reaction time (CVRT) and peripheral vision reaction time (PVRT) that may be assessed using NVT methods (ex. Dynavision Light Board) were both significantly prolonged in concussed patients with visual dysfunction compared to control patients (Clark et al., 2017) Possible implications for this finding include using CVRT and PVRT as tracking measures during RTP protocols as likely reaction times in both variables would normalize with time (Clark et al., 2017). addition to examining deficits noted after concussion in a manner to help guide return to play decisions, various prophylactic visual training regimens may help prevent concussion.

There is evidence that vision training protocols in Division I NCAA athletes may help improve sport performance and skill (Appelbaum et al., 2016; Clark et al., 2012; Feldhacker et al., 2019; Liu et al., 2020) as well as prevent concussions (Clark et al., 2015a, 2020). Recent literature has begun to demonstrate the implied benefit of critical skills garnered through vision training and the possible transfer to sport performance (Liu et al., 2020). High performance vision training was found to be effective in improving the generalized visual motor skills, launch angle, hit distance, reaction time as well as depth perception in Division 1 athletes (Clark et al., 2015c; Feldhacker et al., 2019; Liu et al., 2020). Improvement in these forms of performance measures provides preliminary evidence of potential benefits related to both concussion/mTBI prevention strategies as well as concussion management strategies like NVT. Most notably, in 2010, the University of Cincinnati football team began neurovisual training using various systems including Dynavision D2 light board training, strobe glasses, and tracking drills to help improve their performance and increase safety. After 4 years of neurovisual training they reported a significant drop in their concussion rate (Clark et al., 2015b). Thus, when NVT is implemented as a team-wide exercise, concussion incidence decreases preferentially in those players who receive the training versus those who do not. The current work corroborates those conclusions and expands them with the observed "wash out" where concussions increased when NVT was discontinued (Figure 3). It is possible that developing NVT skills may reduce the incidence of concussion, but those skills are perishable.

Taking training modalities one-step further from concussion prevention to concussion management is the next step in an exciting area of research to expedite neurocognitive rehabilitation and earlier return to play. We are not in a position to claim an evidentiary cause/effect relationship concerning NVT and faster return to play. Further research is needed to demonstrate such cause and effect (Barton & Ranalli, 2020). There is a growing body of evidence, however, supporting rehabilitation-oriented management post-concussion to facilitate recovery (Clark et al., 2014, 2016) and we believe that such evidence should include NVT.

There are few studies that have evaluated the effects of intense neurocognitive rehabilitation on concussion management, but it is a promising field of research being actively pursued (Barton & Ranalli, 2020; Broglio et al., 2015; Clark et al., 2014, Collins et al., 2016). Current concussion consensus statements advocate for concussion management strategies including the following: no RTP or activity for individuals with a suspected concussion, prescribed cognitive and physical rest until asymptomatic, accommodations at school/work as needed, and progressive aerobic exertion-based RTP or activity based on symptoms (Broglio et al., 2015; Harmon et al., 2019; Collins et al., 2016; Kelly, 1999; McCrea et al., 2003). A majority of athletes respond well to this management approach and have a favorable return to full activity. However, some individuals experience persistent symptoms that do not respond to these conventional management strategies.

A report that supports use of intensive rehabilitation, including NVT, for mTBI is a case study of a middle-aged woman injured as a result of a direct blow in a windstorm to the left temporal region (Clark et al., 2014). She had multiple persistent (~ 11 months) deficits after the incident including poor multi-tasking abilities and cognitive failures. An integrated concussion rehabilitation strategy was employed and helped the patient improve. This is in line with strengthening areas of weakness in sports concussion management to help not only rehabilitate an individual but possibly prevent injury in the first place as well (Clark et al., 2014). Both early activity and rest approaches may aid recovery and result in favorable outcomes after concussion.

However, there is increased concern that too much rest may have negative consequences for patients who are slow to recover. There is equal concern regarding how to determine safe exertion levels (Clark et al., 2016, Leddy & Willer, 2013).

One possible result of a concussion is visual dysfunction (Barton & Ranalli, 2020; Rosner et al., 2016; Thiagarajan & Ciuffreda, 2015). Our NVT rehab program is designed to address many of the neuro visual disturbances seen post TBI.

The use of multiple objective measurements in post-concussion management may change decision making regarding return to play timing (Vincent et al., 2020). In the past, multiple concussion studies have cited that the majority of concussions resolve by 7-10 days (Collins et al., 2006, Guskiewicz et al., 2000; McCrea et al., 2003; McCroy et al., 2013). However, recent data from the NFL's Injury Surveillance System suggests that concussions are keeping players off the field longer. In 2009, NFL players missed an average of 6.4 days after suffering a concussion. In 2012, players spent an average of 16 days off the field, indicating roughly a 10 day increase in return to play time. The longer duration is due to better identification and treatment of concussions by the league (Jones, 2013). Furthermore, concussion data collected in the NFL over two consecutive 6-year periods (1996-2001 and 2002-2007) demonstrate a significant decrease in the amount of players returning in <7 days in the latter period of time (Casson et al., 2010).

We firmly believe that brain training prior to injury in conjunction with integrated rehabilitation strategies work together to aid in return to play. The pre-injury brain training we have used is very similar to the rehabilitation modalities used post injury. It is possible that familiarity with the rehabilitation modalities may facilitate and accelerate healing of the brain. If the brain has been conditioned with prior brain training exercise, then there is potentially a "template" that the brain can use to recover post injury.

Limitations

We have not accounted for differences in diagnosis, conditioning or rehabilitation post-concussion for the other AAC teams in this study. Nor did we standardize the criteria for RTP. However, several of the methods employed herein for our athletes are of our own design and only recently published (Clark et al., 2012, 2015a, 2015b, 2015c, 2017). Therefore, we propose that our novel programs, when taken together as a system for preventing and managing concussions, may indeed work together to facilitate RTP as well as concussion mitigation. More work on cause and effect is needed concerning the mechanisms by which our program benefits athletes.

Many concussion studies report concussion rates as numbers of exposures per concussive event. We have reported number of concussions per year in this paper because it is the relevant factor for the medical staff working with the athletes and patients. It is also the way the survey was crafted asking how many concussions you (the athletic trainer for football) had this year.

The survey did ask if the teams utilized specific prevention or rehab programs. Many teams chose to not answer that question resulting in a lot of incomplete data. We cannot rule out other team(s) having similar NVT programs, but none of the responding schools claimed to do NVT comparable to the University of Cincinnati program.

For the University of Cincinnati, the 2017 year was a heterogeneous year for NVT. The prevention component of NVT was discontinued that year but the rehab and management component was maintained. As we have previously published a lower concussion rate (Clark et al., 2015c), we have focused on the NVT to accelerate RTP, which was maintained over all 5 years. Notwithstanding as a retrospective survey we cannot standardize the preseason NVT activity of the players. Future studies are needed to assess the role of NVT pre-season concerning injury severity.

Conclusion

Our study presents new data supporting the use of NVT and integrated post-concussive rehabilitation to decrease return to play time. We reconfirm our previous reports that NVT can decrease concussion injury rates and added to the body of knowledge that the NVT can decrease a team's injury burden by decreasing days lost due to concussion.

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