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A narrative review of sports-related concussion and return-to-play testing with asymptomatic athletes

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Abstract

Objective: The purpose of this literature review was to demonstrate, through examples in the current literature, the cumulative and long-term effects of multiple concussions, postinjury protocols, and the efficacy of current and past return-to-play guidelines.

Methods: A PubMed search was performed using the keywords and key phrases: *concussions and long-term effects*, *concussions and return to play*, and *multiple concussions*. We limited the search to articles that had been published from August 2007 to August 2012 and were specific to human participants. Of the 450 total articles that the search returned, we selected studies specifically demonstrating athletes who were symptom-free, passed neuropsychological testing, returned to play, and were tested in measures of postural control, transcranial magnetic stimulation, electroencephalographic studies, and magnetic resonance imaging spectroscopy.

Results: Selected studies show evidence that, although a previously concussed athlete may be symptom-free and returned to a neuropsychological baseline, the athlete may continue to have prolonged neurological abnormalities that could disqualify them from being ready to return to play.

Conclusion: It appears that some neurological deficits persist beyond the current return-to-play standards and that discrepancy exists between common practices of returning athletes to competition and new standards of published research.

Introduction

Research regarding sports-related concussions and their long-term effects on contact athletes of all ages has seen a staggering expansion in the last few years. The most up-to-date epidemiological research regarding the

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subject states that as many as 3.8 million sports-related traumatic brain injuries (TBIs) occur annually.[1] In addition, because some of the common symptoms of a sports-related concussion may appear as benign to a contact athlete (ie, headache), there is likely underreporting of symptoms to their athletic trainer or team physician,[2] which would mean that the total number of concussions each year is underreported. On average, a college-level contact athlete sustains 470 impacts (all ranges of severity) per season.[3] Not all of these impacts lead to concussions, however; and for mild TBI (mTBI), symptoms such as confusion, dizziness, headache, amnesia, blurred vision, diplopia, nausea, fatigue, or latent insomnia must be reported by the athlete or noticed overtly by surrounding teammates, coaches, or other sideline personnel.[4] Typical sports-related concussions resolve rapidly, with complete symptom resolution in 10 days or fewer,[5] although some atypical concussions leave an individual with prolonged symptoms.[6] However, the cumulative effects of multiple concussions (which are becoming increasingly common among contact athletes) have been shown to result in lower postconcussion neuropsychological (NP) test results than athletes who have not had multiple concussions.[7] The long-term effects of concussions have also been under stringent investigation in recent past, and it was shown that the diagnosis of depression was significantly increased in retired football players who self-reported concussions than for those who did not.[8] Furthermore, the lasting effects of repeated concussions have been linked to chronic traumatic encephalopathy[9] and even early onset of Alzheimer disease.[10]

When an athlete has experienced a concussion, there is often a battery of tests they are taken through to evaluate the status of their neurological function. Often, this begins on the sideline, with NP test sequences that investigate attention and memory functionality—such as Maddock's questions—which are now used rather than the Standard Orientation Questions.[11] A longer postconcussive evaluation tool that is most commonly used is the SCAT3 (Sport Concussion Assessment Tool 3), which was updated and published for universal use by the 4th International Concussion Conference in Zurich and includes Maddock's questions, as well as orientation, immediate memory, concentration, neck examination, balance, and coordination tasks. Following the incident, it is recommended that the athlete who experienced the concussion follow up with a licensed medical practitioner (if they are not immediately taken to a trauma center) for comprehensive examination and determination of clinical status.[11] At this point, a series of tests, including neuroimaging (when warranted), objective gait and balance assessments, and NP tests, is performed to evaluate the injured athlete. Once his or her condition has been determined on all fronts, he or she is placed on both physical and cognitive rest until symptoms resolve,[11] at which point graded exertional protocols (Table 1) and medical reexamination are performed before returning the athlete to play.

Return-to-play (RTP) guidelines have seen a number of changes over the past 25 years. As of 2007, there were multiple accepted concussion grading and RTP guideline systems. Because of some of the long-term effects that had been surfacing in the literature, as well as in the public eye, there became a call to revise the standard RTP criteria that existed.[12,13] In 2008, when experts met in Zurich for the 3rd International Conference on Concussions, a new standard of individualized management protocols was set in place. These concussion management and RTP guidelines at the time were the most universally accepted by athletic trainers and sports physicians, and have since been updated by the 4th International Conference from November 2012. A complete historical recap of highly accepted RTP protocols can be found in Table 2. As medical and research technology has improved, so have methods of postconcussion evaluation. Recently, modalities such as electroencephalography (EEG),[18] functional magnetic resonance imaging (fMRI),[19] and sensitive force plates for balance testing[20] have been considered legitimate evaluation tools for athletes in a state of recovery from mTBI. Recently, there have been examples in the literature using some of these testing modalities to show the likelihood that many athletes that are permitted to return not only to physical activity but also to full-contact competition may not be ready to do so despite being symptom-free and passing the battery of standard RTP tests (ie, NP, balance, exertional tests).

Although the standards of concussion grading and RTP guidelines are changing, the annual number of documented concussions suffered by athletes in contact sports at all levels is not decreasing, and, in fact, may be increasing. The purpose of this literature review is to investigate examples from the recent literature to determine whether or not athletes with head trauma are ready to return to competition even though they are symptom-free and passed objective neuropsychological tests.

Methods

We performed a search using PubMed for pertinent articles on the subject of sports-related concussions,

Table 1 Zurich guidelines, graded return to play[11]

State of rehabilitation	Functional exercise at each state of rehabilitation	Objective of each stage
No activity	Complete physical and cognitive rest	Recovery
Light aerobic exercise	Walking, swimming, or stationary cycling, keeping intensity of 70% of max. predicted heart rate; no resistance training	Increase heart rate
Sport-specific exercise	Skating drills in hockey, running drills in soccer, no head impact activity	Add movement (noncontact)
Noncontact training drills	Progression to more complex training drills, eg, passing drills in football and ice hockey, may start progressive resistance training	Exercise, coordination, and cognitive load
Full-contact practice	Following medical clearance, participate in normal training activities	Restore athlete's confidence and functional skills
Return to play	Normal game play	

evaluation of long-term effects of these concussions, and recovery and RTP. We applied a filter that allowed only a yield of articles published within the range of August 2007 to August 2012 and filtered out any studies that did uniquely include human participants. The key phrase search of *long term effects of concussions* yielded 266 articles. The search of *concussions and return to play* produced 101 articles published in the previous 5 years. A third search with PubMed was performed using the phrase *multiple concussions*, which yielded 65 more studies. Lastly, the search of *effects of multiple concussions* was performed, providing another 18 articles. From the total yield of these articles, we selected those studying contact athletes who experienced recent mTBI but had since been symptom-free according to a battery of NP tests and had since been cleared for RTP to see whether or not they had significant neurological abnormalities for a prolonged period post-RTP.

A majority of the studies dealt with similar testing and protocols for affected, concussed athletes; however, the studies were performed on the test group within only a week or two (acute and subacute phases) of the test participants' concussions. Because of the nature of our interest on the lingering effects on athletes who were in the subacute or chronic phase and currently back on the field, we did not review those studies. For the purposes of background information for our review, we also chose a number of studies regarding current and past standards of concussion grading and RTP guidelines, as well as cohort studies, which examine the long-term effects on retired contact athletes who have outward effects later in life.[8,21] We examined each of the studies we selected for any bias that could have led to significant alterations in their results. For this possible exclusion from our review, we ensured that the conclusions drawn from these studies matched the individual results from their research and had statistical significance. We inspected data regarding project funding, if shown, to see if there may have been any conflict of interest that could potentially influence their conclusions or results. We are aware that, even with our very narrow selection criteria, there may have been articles published having similar data or results that were missed and were therefore not included in the study; but we felt that these studies reviewed below were fair studies that adequately demonstrated chronic effects of mTBI in players who were already back on the field. There were no compensations, contributions, or any other incentives that influenced our search or selection criteria.

Narrative summary of selected examples

A majority of the studies that showed objective deficiencies in concussed athletes did so within a short period (ie, 72 hours-2 weeks) following the injury. These deficiencies in the acute and subacute phases of concussion are expected and obvious. However, the following examples are studies that show prolonged objective abnormalities in athletes who were symptom-free, passed NP tests, and were currently returned to competitive play. The samples studied, tests performed, and other salient results are presented in Table 3.

A recent study published in February 2012 in *Clinical Neurophysiology* showed that EEG abnormalities persist in formerly concussed athletes who have already been allowed to return to play as compared with nonconcussed teammates. Initially, 380 NCAA Division I athletes who had no concussion history and were set to participate in high-impact sports were recruited and tested for a baseline. These tests included

Table 2 Historic RTP standards from published research

Guideline (year published)	Concussion grade: 0	1	2	3
Nelson et al (1984)[14]	RTP with symptom-free, ask about symptoms during the remainder of activity, remove if symptoms return	Grade 1 and 0 grouped together	Remove from activity, no RTP unless symptom-free, see neurosurgeon if symptoms do not clear within 2 d	Remove from activity no RTP until cleared by neurosurgeon, urgent consult if increase in symptoms observed
Wilberger & Maroon (1989)[15]		1st—Remove from activity, RTP 1 wk after start of being symptom-free 2nd—RTP 2 wk after start of being symptom-free, and normal CT study 3rd—Terminate athlete's season	1st—RTP 2 wk after start of being symptom-free 2nd—RTP 1 mo after start of being symptom-free and normal CT 3rd—Terminate athlete's season	1st—RTP 1 mo after symptom-free, and normal CT study 2nd—Terminate athlete's season
Colorado Medical Society (1991)[16]		1st—RTP same day if symptom-free for 20 min 2nd—Remove from activity 3rd—Terminate athlete's season, RTP in symptom-free for 3 mo	1st—Terminate activity, may RTP if symptom-free for 1 wk 2nd—Consider terminating athlete's season, RTP if symptom-free for 1 mo 3rd—Terminate athlete's season, may RTP next season if symptom-free	1st—RTP after 1 mo if symptom-free for latter 2 wk 2nd—Terminate athlete's season, advise against return to contact sports
Cantu (2001)[17]		1st—1 wk if symptom-free 2nd—2 wk if symptom-free for 1 wk 3rd—Out for season, may RTP next season if symptom-free	1st—2 wk if no symptoms for 1 wk 2nd—Minimum of 1 mo, then RTP if symptom-free for 1 wk 3rd—Out for season, may RTP next season if symptom-free	1st—Out for minimum of 1 mo, then RTP if symptom-free for additional 2nd—Out for season, may RTP next season if symptom-free
4th Zurich (2012)[11]		Concussion grading system no longer in use: Athletes are evaluated on a case-by-case basis. RTP is graded (Table 1) and allowed once the athlete is symptom-free and passes SCAT3 evaluation, NP testing measures, and objective balance assessment. See Table 1 for protocols of current graded RTP standards.		

CT, computed tomography; *RTP*, return-to-play; *SCAT3*, sport concussion assessment tool 3.

computerized balance and EEG data. Within 6 months of baseline testing, 49 of the original participants experienced a single concussion episode, all of which were considered Grade I mTBIs using Cantu's revised grading guidelines.[17] Within 7 to 10 days, all participants were clinically asymptomatic and allowed to RTP after clearing the Cooperative Ataxia Rating Scale test. On days 7 and 14 postinjury, NP tests were administered, consisting of the subjective symptom rating scale (to evaluate the athlete's symptoms), symbol digit substitution test (to evaluate working memory and the ability to process information quickly), and the trails "B" test (to demonstrate the proficiency of scanning and processing). In addition, EEG as well as postural/balance analysis was performed at days 7, 15, and 30 and also at 6 and 12 months. Results demonstrated that center of pressure (COP) area percentage increase from standing with eyes open to eyes closed (a manifestation of proprioceptive control deficit) was still as high as an average 15% greater than at baseline testing at day 15 and an average of 3% greater than baseline at day 30. The EEG portion of the study also showed that participants who had greater than or equal to 20% alpha suppression levels as compared with their baseline examination did not return to preinjury status during the 12 months of observation following the injury.[20]

Another pertinent study on the prolonged effects of sports-related concussion was performed in 2011 by De Beaumont et al[24] (published by the *Journal of Athletic*

Table 3 Evidence table

Reference	Patient population	Test(s)	Design	Results	Comments
Slobounov et al, 2012	Penn State University, 380 contact sport athletes (football, rugby, ice hockey, etc)	NP, EEG, and objective balance testing	Baseline testing to all 380 participants, then follow-up testing of the 49 who sustained concussions (at days 7, 14, and 30 and at 6 and 12 mo post-mTBI)	For concussed participants, an increase COP area % was observed, on ave, 15% higher than baseline at day 15 post-mTBI, 3% on day 30. EEG study showed that those with >20% alpha suppression at 7 d post-mTBI never returned to baseline levels by 12 mo.	Decreased proprioceptive ability and lingering effects of mTBI on the motor cortex in chronic-phase, post-RTP athletes
De Beumont et al, 2011	21 Active college level football players w/ concussion at least 9 mo prior, and 15 w/o hx of concussion	NP testing to determine asymptomatic status, then COP tests in quiet standing	All participants performed two 30-s trials in quiet standing	Significantly greater COP oscillations, greater variations in sagittal plane sway in chronic-phase mTBI group compared with control	Decreased proprioceptive ability in chronic-phase, post-RTP athletes
Henry et al, 2011	10 Active college-level football players with hx of mTBI, and 10 w/o hx of concussion	NP testing to determine asymptomatic status, then fMRI spectroscopy to look for metabolic changes in subacute/ chronic mTBI group	fMRI to concussion athletes 6 mo postinjury compared with injury-free teammates	Decrease of *N*-acetylaspartate levels in the M1 cortex in chronic-phase mTBI group compared with control	Decreased *N*-acetylasparatate levels shown in previous studies to correlate with acute neuronal damage and mitochondrial dysfunction[22,23]
De Beumont et al, 2007	University of Montreal, varsity football players, 15 with 1 concussion, 15 with 2-5 concussions, and 15 with no concussions	NP testing to determine asymptomatic status, then TMS to all participants	TMS performed to all athletes to compare all 3 groups	Elongated CSP following TMS to concussion group compared with control. Also, an increase in CSP from multiple-mTBI group to single-mTBI group	Lingering effect of mTBI in chronic-phase, post-RTP athletes
Slovounov et al, 2007	Penn State University, 160 male and female varsity rugby athletes with no hx of concussion	NP testing to baseline and after concussion, stereovisual testing in virtual reality setting using body sensors and force plate	Baseline stereovisual testing, retest for 39 athletes postconcussion at days 10, 17, and 30. Nine athletes having 2nd concussion in 1 year's time retested at days 10, 17, and 30	At day 17 post RTP, 1st concussion group showed a 40% decrease of COP coherence to "moving room scene," 2nd concussion group showed 60% decrease on day 17, while asymptomatic and again having returned to play. At day 30 in the 2nd concussion group, there was still a 35% decrease from baseline testing	Decreased rate of recovery as seen in proprioception and body awareness/ coordination study, despite RTP in single- and multiple-concussed athletes

COP, center of presure; *EEG*, electroencephalography; *fMRI*, functional magnetic resonance imaging; *mTBI*, mild traumatic brain injury; *NP*, neuropsychological; *RTP*, return-to-play.

Training). It demonstrated chronic neurological abnormalities in concussed athletes compared with those in a control group. This case-control study compared 21 college football players who had concussions at least 9 months before testing to 15 players who had not had documented concussions. Their selection criteria ensured that the participants had no history of alcohol or substance abuse, no TBIs unrelated to contact sports, and no history of neurological abnormalities or disabilities of any kind. Each of the athletes who reported having documented concussions in the test group was considered to be asymptomatic according to the Post-Concussive Symptom Scale. The design of the study was to have each participant perform postural control assessments. These included two 30-second trials, which showed a greater variance in COP displacement during *quiet standing* (defined as feet shoulder-width apart with arms relaxed at sides). The variance included greater amplitude in the formerly concussed participants' sway, as well as greater irregularity of sway in the sagittal plane.[24]

Another recent article by Henry et al,[19] published in 2011 in *BMC Neurology*, performed functional imaging studies on concussed athletes in both the acute and chronic phases of the injury. This study selected 10 college-level football players who had experienced a recent mTBI, as well as a control group of their teammates who had never experienced a concussion or other neurological injury. They performed MRI spectroscopy to determine whether or not metabolic changes continued into the chronic stage of recovery (greater than 3 months) while the patient had been back to competition or full-contact practice/scrimmage. All 20 players involved in the study were without any previous history of alcohol or substance abuse, psychiatric illness, learning disabilities, neurological disorders, or non-sports TBI. Magnetic resonance imaging spectroscopy was performed using a Siemens 3-T MRI scanner within 1 to 6 days and then again 6 months after the injury occurred in the mTBI group. The dorsolateral prefrontal cortex and primary motor (M1) cortex were examined. The results of the 6-month postinjury MRI showed no difference in the dorsolateral prefrontal cortex between the test group and the control group, but there were decreased *N*-acetylaspartate levels in the M1 cortex.[19]

Another pertinent study showing long-term effects of concussions persisting in athletes who were already back on the field using transcranial stimulation was performed by De Beaumont et al[25] from *Neurosurgery* in 2007demonstrated prolonged neurological effects of mTBI. Forty-five college football players from a university in Montreal were placed into 3 groups: those who had experienced 1 concussion, another group of those who had had between 2 and 5 concussions, and a control group of individuals never having experienced known neurological insult. Before testing, it was shown through a battery of NP tests that all 45 of the players were asymptomatic and outwardly functioning within normal limits. However, it was shown that individuals from each of the 3 groups varied significantly in the results of transcranial magnetic stimulation (TMS) testing. These tests demonstrated that all participants that had experienced a concussion had an elongated cortical silent period (CSP) following TMS as compared with the control group. The "multiple concussions" group had a statistically significant increase in CSP also, as compared to the "single concussion" group.[25]

Another study, that of Slobounov et al published in *Neurosurgery* in 2007, demonstrated the differential rates of recovery in those athletes who had more than one mTBI. Their study included both men and women between the ages of 19 and 25 who had concussions within 6 months of their baseline preseason testing. They narrowed down their research to 38 athletes who had mTBI, 9 of whom had a second concussion within 1 year. In any event, they were evaluated using stereovisual testing, during which each participant was instructed to stand on a balance platform and whole body movements in synchrony with visual scenes of a moving room displayed on a video projector screen in front of them for 30-second trials. Their COP kinematic tendencies, measured in relative coherence to the moving room sequence, were evaluated using the MATLAB program (in other words, how closely they were able to coordinate their movements to the moving room on the video screen). In addition, special sensors monitored torso movements during the trial. Preinjury, the population of athletes recorded COP movements with between 82% and 85% coherence to the moving room; and torso movements correlated between 77% and 79%. Without providing exhaustive data from the study, its significance is that all involved athletes were symptom free and returned to competition within 10 to 15 days of the concussions; and yet the percentage of COP coherence at day 17 was averaged to 43.5% in those who were recovering from their first documented concussion and 26.5% in those who were recovering from a second. Day 30 data demonstrated a significant trend, where participants coming off of their first concussion had a COP coherence of 76.5%, still lower than their baseline preinjury scores, and where those with a second concussion had 49.5%.[26]

Discussion

The current review took a look at several recent examples in the literature to examine the efficacy of RTP guidelines and the methods used to evaluate an injured athlete's postconcussion status and physical preparedness to be back on the field. The subject of concussions and the return-to-play guidelines have been on the forefront of discussion regarding contact sports as of late, with a substantial increase in research within the past decade. The studies above all demonstrate, to varying degrees, that the average adolescent to young adult athlete has residual neurological deficits after having been returned to competitive practice and competition. The *Clinical Neurophysiology*, *Journal of Athletic Training*, and *Neurosurgery* articles above all demonstrated significantly increased variance of COP in those athletes who had sustained recent concussions yet were since back on the field of play, all of which suggest that there are lasting proprioceptive deficits beyond RTP.[20,24,25] It would seem that athletes who are back on the field with balance and body awareness insufficiencies could have a higher likelihood of other types of bodily injury, both of contact and noncontact etiology. The fMRI study from *BMC Neurology* showed that those involved in mTBI 6 months before testing had decreased *N*-acetylaspartate level in the M1 cortex, which has been implicated previous studies[11,22,23] as a marker for neuronal damage and mitochondrial dysfunction. These changes suggest that the effects of mTBI are persistent and may indicate irreversible damage.[19] The De Beaumont et al[25] *Neurosurgery* article used yet another assessment modality to demonstrate residual neurological issues, showing significant increases in CSP following TMS. Here, strong evidence was again shown of lingering effects that exist past RTP, and also that a lengthening of the CSP was correlated with concussions of a more severe nature (ie, with loss of consciousness, amnesia at the time of injury, or atypical continuation of symptoms).

As previously stated, the 4th International Conference on Concussion in Sport was held, again, in Zurich, Switzerland, to continue raising the standards of concussion evaluation, management, and RTP for contact athletes. Their updated consensus statement, published in March 2013, did mention some advanced testing modalities for concussed athletes such as functional MRI, PET scans, diffusion tensor imaging, and functional connectivity; however, they stated that these are not yet useful for everyday measurement of an athlete's readiness for RTP because of the limited research for each type. Perhaps upcoming research will demonstrate practical utility of these newer, advanced modalities of testing, so they can be used to evaluate athletes before returning them to play—even though they may be symptom-free and have passed NP testing, basic objective balance testing, and exertional protocols—to preserve their careers and quality of life years later. Although an athlete is symptom-free and has been tested by the most state-of-the-art NP examination protocols, the objective signs seem to point to a continuing issue.

In clinical practice, a physician must take into account both the symptoms and signs from a patient's history, examination, and imaging to accurately make a diagnosis or determination on the patient's health status. Take, for example, a disc herniation patient, whose radicular pain centralizes and abolishes in the initial visit. After 7 to 10 days of diligence with end-range loading exercises, the patient may be symptom-free, yet would not fully have a fully healed annulus fibrosis, should the affected disc be re-examined with high-resolution MRI. That patient would be advised, at least for a period, not to return to high-impact, strenuous activities even if they are currently in a subjective state of being symptom-free and likely desiring to get back into competition or activity. The same frame of mind seems prudent when considering the RTP of a young contact athlete whose brain is recovering from a concussion, although he or she is not experiencing symptoms.

Limitations

There are a number of limitations to our research. We did not perform a systematic review; thus, how we selected the articles and how they were summarized may include author bias. Our sample size is small because of the limited amount of research being done on the lingering effects of concussions in athletes who are already returned to play and are back to full contact. We are also aware that other research studies have been published that may have been missed by our search methods.

Future research/suggestions

It seems as though there is a need for further research into whether athletes are truly ready to return to play after concussion. Areas of research should seek a cost-effective way to evaluate accurately for the presence of residual signs of mTBI, which would allow its use by physicians and athletic trainers to determine whether their athlete is safe to return to sport. It may prove helpful to evaluate consenting contact athletes to baseline NP tests, COP evaluations, and EEG analysis and then follow up each week throughout the competition season, regardless of whether or not the participant has ever become symptomatic of a concussion, to see if subclinical situations of brain injury exist and are cumulative.

Conclusion

According to examples from the literature, contact athletes who are symptom-free, have passed NP and basic balance testing, and have been returned to play have residual functional deficits according to advanced testing modalities. This may indicate that new standards of pre-RTP testing are needed for evaluation of a post-mTBI athlete who otherwise seems ready to be back on the field.

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