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Visuomotor Reaction Time Performance in Collegiate Contact and Limited Contact Team Sports

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Abstract: *This study assessed baseline reaction time (RT) performance of collegiate student-athletes participating in a contact team sport. The goal was to determine if significant differences in visuomotor RT existed between athletes who had previously sustained a concussion and were now cleared to play their respective sport against a control population of peers who have not sustained a concussion. This study employed a cross-sectional, quantitative, correlational study design. 269 Athletes from contact team sports were identified for potential inclusion. 62 enrolled in the study and 60 participants completed the study. Participants completed three tests to assess their reaction time: Trail Making Test, Ruler Drop Test, and Light Sensor Reaction Test. Participants completed intake paperwork indicating if they had a previous concussion. Participants were 70% female (n=42) and 30% male (n=18). Over 38% of participants (n=23) indicated a prior history of at least one diagnosed concussion or TBI. Mean age was 20.7 ± 1.5 years. No significant differences were found between groups (p>0.05). Collegiate athletes who recovered from a concussion do not demonstrate delays in RT compared to their non-concussed peers. Contact sport athletes should be allowed to return to play their respective sports when they have met their established healing goals via objective performance evaluation and subjective emotional readiness to play.*

Keywords: Concussion; reaction time; visuomotor; contact sports; athletes; experimental group

Introduction

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Concussions and other Traumatic Brain Injuries (TBI) from contact sports are a topic of great importance as researchers attempt to establish connections between repeated head injuries and future neurodegenerative conditions such as Chronic Traumatic Encephalopathy (CTE), dementia, and Parkinson’s Disease (PD). It is estimated that between 1.6-3.8 million concussions occur annually in the United States, with 10% of all contact sport athletes (i.e., those athletes who regularly make physical contact between themselves and their opponents or the environment) suffering at least one concussion annually (Satarasinghe et al., 2019). Bellomo et al. (2022) found that former collegiate and professional athletes who participated in contact or collision sports such as soccer, boxing, or American football had significantly higher rates of developing PD and CTE. While the exact mechanism of action is unclear, Buckland et al. (2022) indicated that the biggest preventable risk factor in developing CTE was exposure to repeated head injury. In a case-control study, Chen et al. (2022) indicated that individuals with two or more concussions who had a history of playing competitive soccer were up to four times more likely to develop some form of motor neuron disease over individuals who did not play competitive soccer or had a history of concussions.

Several different symptom factors have been determined to play a considerable role in prolonging return to play time: Balance issues, difficulty concentrating, light sensitivity, drowsiness, ongoing fatigue, and poor memory recall (Wang et al., 2022). Establishing recommendations for using Reaction Time (RT) as a tool for assessing athlete return to play status post-concussion may ultimately depend on the demands of the sport itself. RT for athletes in agility driven sports consistently demonstrate faster RT than athletes from non-agility driven sports (Pojskic et al., 2019). Further, Caccese et al. (2020) indicated athletes in limited and full contact sports had faster RT than athletes participating in noncontact sports. When preseason testing is too costly or time intensive, norm-based scoring to establish post-concussion recovery time may be the most desirable outcome for gauging recovery time and return to play in individual athletes (Caccese et al., 2021). Similarly, Arnett et al. (2023) found that the use of algorithms to determine if a collegiate athlete had recovered from a concussion was a valid measurement even when no baseline data was available for the athlete prior to the concussion. The major concern is that persistent post-concussion symptoms will not only affect an athlete's ability to play their sport competitively, but will also negatively impact their activities of daily living, such as vision and sleep problems (Zenoozi et al., 2024). This, in turn, can create a localized environment where one's quality of life is greatly diminished due to ongoing concussion symptoms.

In addition to neurological considerations, orthopedic injury is another potential complication athletes may encounter when they return to play post-concussion. Athletes were shown to be at a greater risk of lower extremity injury following a return to play post-concussion, which may have been attributed to delays in RT, processing speed, attention, and concentration (Ray et al., 2022). However, the authors found no lasting delays in RT after those athletes who sustained a sport-related concussion were cleared by healthcare professionals to safely return to play. Similarly, Harada et al. (2019) indicated that athletes with multiple concussions were at the greatest risk of sustaining a lower extremity injury over athletes with one or no prior history of concussions. Conversely, Engeroff et al. (2019) argue that both lower and upper extremity injury risk can be mitigated through the use of visuomotor reaction time training.

Light sensors for visuomotor RT training have been used extensively. Studies that have used light sensor training have found that short term improvements in RT are not sustained when training is discontinued, but will last long term when training is maintained (Hulsdunker et al., 2021). Using a light stimulus has also been found to a be a reliable measure for assessing RT in team sports (Gutierrez-Vargas et al., 2020).

The purpose of this study was to assess baseline RT performance of collegiate student-athletes participating in a contact or limited contact team sport. The goal was to determine if significant differences in visuomotor RT existed between athletes who had previously sustained a TBI or concussion and were now cleared to play their respective sport against a control population of peers who have not sustained a TBI or concussion.

Methods

Research Design

Our research paradigm was a quasi-experimental, cross-sectional, between-subjects study with natural grouping. There was no random assignment of groups as groups were determined based on each participant's history with concussions. Participants were all given the exact same treatment with grouping based solely on the participant's self-reported, pre-existing history of concussions.

This study was approved by the Park University Institutional Review Board (IRB) and assigned tracking number 1679217_1 Nov2022_1940. All subjects were informed prior to study enrollment of the benefits and risks of study participation. All subjects gave verbal and written consent to participate and signed an IRB-approved informed consent document prior to testing.

Participant Selection

We identified a potential participant pool based on the available athletic teams at our institution. Potential participants were not directly contacted by the research team, and researchers organized participation through each athlete's respective head coaches. Participation was completely voluntary and no compensation was provided to participants. Each participant was informed of their raw scores and a basic score interpretation.

The main inclusion criteria for this study were: 1) Participants were current members of a team contact sport (defined as any of the following: Baseball, softball, indoor volleyball, beach volleyball, soccer, and basketball) at their university, 2) Participants were not being treated for a current concussion or other TBI. A total potential participant pool of two hundred sixty-nine athletes were identified as meeting the inclusion criteria for possible study inclusion. Of these potential participants, two hundred seven declined to participate, and two did not complete testing. A total of sixty participants completed the study.
Participant demographic information was collected prior to test administration and can be seen in Table 1. Participants indicated on their intake form their history with concussions and TBIs. This allowed for post hoc grouping of participants into the control group (i.e.,

participants who indicated no history of TBI or concussion) or experimental group (i.e., participants who indicated they have had one or more concussions or other TBIs).

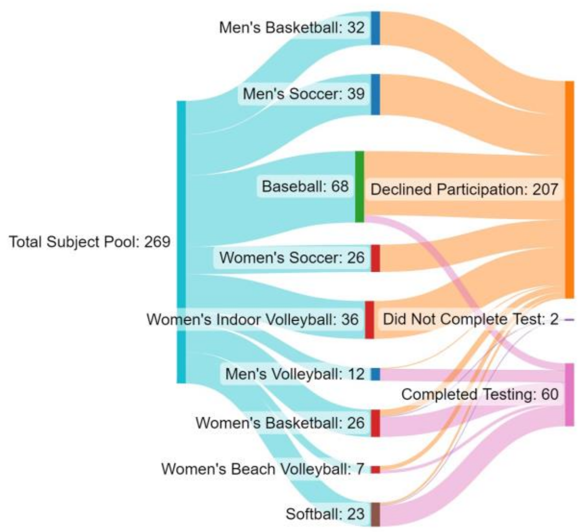

Figure 1 *Participant Attrition Rates*

Table 1 Participant Demographic Data

Demographic Category	**Frequency**	**Valid Percentage**
Gender		
Male	18	30.0
Female	42	70.0
Age		
18	4	6.7
19	11	18.3
20	12	20.0
21	14	23.3
22	11	18.3
23	7	11.7
26	1	1.7
Average Age		
20.7 ± 1.5 years		
Median Age		

	21 years

Materials

Standard twelve-inch wood rulers were used to assess participant's reaction in the ruler drop test. The trail making tests required pen, paper, and a Carolina Sports Timer stopwatch for recording time to completion. The light board reaction test employed the use of eight Light Trainer V3 sensors mounted securely to a table with Velcro and magnetic connections. These were sequenced via the Light Trainer iOS mobile app v.1.1.1.

Procedure

The authors solely tested each participant and no facilitators or proxies acting on behalf of the research team were employed in this study.

Ruler Drop Test

The Ruler Drop Test was adapted from Davis et al. (2000). Verbal instructions were given to each participant prior to initiating the test. Participants were seated with their dominant forearm resting on the corner of a table. Their dominant hand was positioned with a cylindrical grip. A tester would hold a ruler perpendicular to the participant's hand and drop the ruler at random intervals. The participant was tasked with catching the ruler as fast as possible. Participants completed three trials and the distance the ruler fell (in *cm*) was recorded.

Trail Making Test

The Trail Making Test was adapted from Arnett and Labovitz (1995). Participants were seated and given verbal and visual instructions prior to initiating the test: Part A would require participants to draw lines to connect circles numbered 1-24 in ascending order. Part B of the Trail Making Test has circles labeled with both numbers (1-12) and letters (A-L). Participants were required to draw lines connecting circles in an ascending pattern, but alternating between numbers and letters (i.e., 1-A-2-B-3-C-etc.). Participants used a ball point pen to complete the test and were instructed to keep their pen nib in contact with the paper at all times, while trying to connect the circles as quickly as possible. A demonstration was conducted with each individual participant using a Trail Making Test sample diagram showing how the circles should be connected. Participants were finally informed they needed to break the surface of each circle with their ink before moving on to the next circle. Researchers would inform participants if they made an error and allowed them to go back and correct their error prior to completion of each test. Trail Making Tests A and B, as well as the sample used can all be seen in Figure 2. The standard Trail Making Test A and B versions were administered to each participant once with time to completion (in *s*) being recorded for each test via stopwatch.

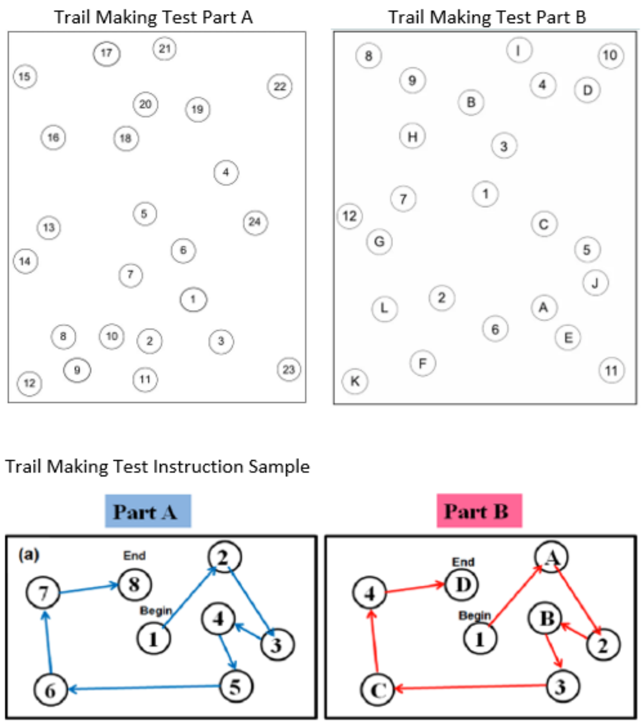

Figure 2 *Trail Making Tests A & B, Including Instructional Samples*

Light Board Reaction Test

The Light Board Reaction Test was modified from the Speed, Power, Agility, Reaction, and Quickness (SPARQ) Boxing Light Board Test protocol. Participants were given verbal and visual instructions prior to initiating the test, as well as physical practice time of approximately 30 seconds to become acquainted with the sensitivity of the light sensors. The sensors were positioned in a novel pattern of an outer square and inner diamond to challenge both RT and spatial recognition of a stimulus. After completion of their practice time, participants underwent two 30-second trials while staying seated. Participants were instructed that they could use one or both hands to hit the sensors. Using the Light Sensor app, a randomized pattern was generated with one sensor being illuminated for a period of two seconds, or until the sensor was deactivated by participant striking. Participants would strike as many illuminated sensors as possible in each 30-second trial. Average striking time in seconds (i.e., the average amount of time it took participants to strike an illuminated sensor) was recorded for each trial.

Results

Data were analyzed using JASP 0.18.1. Of the 269 potential participants identified, 60 completed the testing in its entirety. Participants were grouped post hoc into the experimental or control group based on their self-reported prior history of concussions or TBIs. Participants were 70% female (n=42) and 30% male (n=18) and over 38% of participants (n=23) indicated a prior history of at least one diagnosed concussion or TBI. Mean age was 20.7 ± 1.5 years.

Normality was tested using a Shapiro-Wilk test of normality which yielded significant results ($p<0.05$), indicating the data were non-normal. Student and Mann-Whitney independent samples T-Tests were conducted and all results were insignificant ($p>0.05$) (Table 2).

Table 2 Independent Samples T-Test

	Test	Statistic	df	p
Ruler Drop Test Average	Student	1.170	58	0.247
	Mann-Whitney	492.500		0.312
Trail Making Test A	Student	0.066	58	0.947
	Mann-Whitney	480.500		0.407
Trail Making Test B	Student	-1.176	58	0.245
	Mann-Whitney	378.000		0.478
Light Board 1 Average	Student	-0.951	58	0.346
	Mann-Whitney	420.000		0.939
Light Board 2 Average	Student	-1.039	58	0.303
	Mann-Whitney	428.000		0.976

Mean differences (Table 3) showed nearly identical performance between groups, with both groups showing improvement in Light Board RT from trial 1 to trial 2. The TBI group averaged 15.3cm (±4.6cm) in the ruler drop test, 16.9s (±4.4s) in Trail Making Test A, 41.7s (±10.8s) on Trail Making Test B, and 0.476s (±0.06s) and 0.463s (±0.055s) for Light Board trials 1 and 2, respectively. The CON group averaged 13.9cm (±4.6cm) in the ruler drop test, 16.8s (±5.5s) in Trail Making Test A, 48.3s (±25.2s) on Trail Making Test B, 0.499s (±0.106s) for Light Board trial 1, and 0.490s (±0.114s) for Light Board trial 2.

Table 3 Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation

Table 3 Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Ruler Drop Test Average	TBI	23	15.319	4.637	0.967	0.303
	CON	37	13.882	4.615	0.759	0.332
Trail Making Test A	TBI	23	16.903	4.423	0.922	0.262
	CON	37	16.813	5.470	0.899	0.325
Trail Making Test B	TBI	23	41.746	10.786	2.249	0.258
	CON	37	48.284	25.213	4.145	0.522
Light Board 1 Average	TBI	23	0.476	0.060	0.013	0.127
	CON	37	0.499	0.106	0.017	0.212
Light Board 2 Average	TBI	23	0.463	0.055	0.011	0.119
	CON	37	0.490	0.114	0.019	0.233

Discussion

The results indicated no significant differences in visuomotor RT performance between collegiate athletes with or without a prior history of concussion. These results suggest that athletes who are fully recovered from a concussion do not have a reduction in RT compared to their healthy peers. Previous use of the ruler drop test to assess post-concussion recovery in high school athletes indicated that RT did not return to pre-concussion levels until 14 days post-injury (Del Rossi, 2017), highlighting the need to give young athletes a safe space to recover without pressure to return to play before fully healing. It was unlikely that between groups significance would occur for RT after an athlete has completely recovered from an acute concussion. As this study employed a cross-sectional design, we are unable to make any conclusions regarding long-term RT changes post-concussion.

One of the biggest concerns with post-concussion management is reinjury, or sustaining a second concussion before the first has time to adequately heal. Athletes who sustain multiple concussions in the same sports season display measurable reduction in cognitive and motor performance (Pearce et al., 2014). The potential impairments of post-concussion syndrome can also make informed decisions on return to play status. Attempting to return to play too quickly without the full resolution of concussion symptoms poses a much greater risk of having an unsuccessful return, which has been shown to have an overall negative impact on the individual’s socioeconomic and psychosocial statuses (Karmali et al., 2022). However, interventions should aim to not only resolve symptoms but to also improve return to play times. An early intervention of head-neck cooling administered immediately after a suspected concussion was associated with improved symptom management and a 44% shorter time to return to play (7 days vs 12.5 days) in professional ice hockey players (Gard et al., 2021).

In a qualitative study, male and female collegiate athletes noted that the pressure to perform a desire to play, and fears of repercussions from both coaches and faculty were at the forefront of concerns for athletes who were faced with the task of needing to report concussion symptoms on behalf of themselves or a teammate (Kneavel et al., 2021). Athletes also noted a desire for their faculty instructors to be more understanding and empathetic with their overall recovery timeline, which may interfere with a normal class schedule. With elite level, college-aged athletes being under greater pressure to perform, establishing normative data could help provide more objective measures for safe and successful return to play for athletes recovering from an acute concussion. This could also reduce the instances of athletes falsifying their symptom reporting in an attempt for quicker return to play. When the Behavior-Aware Partially Observable Markov Decision Process was implemented, premature return to play of concussed athletes was reduced by 44% and increased health-adjusted athletic exposures (i.e., the time an athlete spends participating in the sport and exposes the athlete to the risk of injury) by up to 3.63 additional instances (Garcia et al., 2023). This would suggest that a slower return to play from the onset of injury would lead to improved patient outcomes and decrease the risk of reinjury when completed in a controlled environment, such as the team practice facility or in a one-on-one training environment.

As the overwhelming majority of second concussions occur within 10 days of the initial injury (Moreland & Barkley, 2021), it is important for practitioners, coaches, and athletes themselves to not only recognize the severity of the initial injury, but also establish and maintain appropriate return to play measures that are objective and do not bend to the subjective desire of the athlete, coaches, or administrators to return to play faster than safely possible. Further, the authors indicated the best form of concussion management is preventative care. Athletes should be afforded ample time for cognitive and physical rest after the onset of acute concussion symptoms. A potential barrier is finding reputable online patient education materials that will help athletes, families, coaches, and organizations in their return to play decision making. Many independent organizations publish education materials at reading levels higher than the 6th grade reading level recommended by both the American Medical Association and the National Institutes of Health (Roy et al., 2024). The authors go on to state that the most accessible materials are generated by academic and nonprofit institutions, whereas private, for-profit organizations tended to publish more complex and higher reading levels than the typical literacy level of the average American. As this research targets college-affiliated athletes, institutions of higher learning need to have education materials available and accessible to their students as a whole.

Additional consideration should be given to college athletes with a history of concussions in their youth. A thorough medical history should be created by institutions on all of their athletes, noting instances of confirmed or suspected concussions and mild TBIs. Researchers found better outcomes with elite-level youth rugby players when they were kept out of competition for at least seven days post-concussion (Gardner et al., 2024).

Athletes may also not be able to recognize concussion symptoms in themselves or others. Hosokawa et al. (2023) noted that athletes were largely unaware of emotional signs and symptoms of a concussion, such as changes in mood and anxiety levels. Athletes may also be physically ready to return to sport prior to their psychological readiness to return to sport (Lassman et al., 2022). When an athlete expresses uncertainty in their psychological and emotional well-being regarding concussion recovery it is imperative that coaches and/or medical staff interpret that as a sign the athlete is not ready to return to play due to risk of reinjury and performance breakdown. Based on the findings of this study, the conclusion is that contact sport athletes should be able to return to play their respective sports when they have met their established physiological healing goals via objective performance evaluation, as well as when the athlete subjectively feels psychologically ready to return to sport. Coffey et al. (2018) found that professional and semi-professional soccer players often overreported concussion symptoms even when they did not have an officially diagnosed concussion. However, only 60% of players reporting concussion symptoms were held back from play which suggests that players are doing better with identifying and reporting symptoms, but coaching staffs may still need additional training or educating to make better judgement calls about withholding athletes from play who have concussion symptoms. Conversely, Taft & Ennion (2021) found in their study that nearly 70% of concussed younger athletes were unlikely to adhere to return to play guidelines, even when the athlete knew they were not completely recovered and had a good understanding of their return to play guidelines. The authors went on to note that players described their reasons for noncompliance as a mixture or peer pressure, intrinsic motivation to play, and ignorance of their health condition.

Much of the subjective judgement calls can be mitigated by having objective return to play criteria. High school athletes who were subjected to a seven-step return to play protocol had longer return to play times (20.2 ± 13.9 days) but found that return to play was better tolerated due to complete resolution of all symptoms prior to returning to play (Tamura et al., 2020). The authors also indicated that younger athletes required a longer time to return to light activity than older athletes. This would suggest that the interdisciplinary team should monitor younger players more closely when they are recovering from a concussion or other mild TBI.

Tucker et al. (2024) noted that return to play post-concussion is highly dependent on symptom presentation and progression over the first 48 hours post-concussion. An athlete with a head injury assessment score higher at two hours post-concussion than their scores at 48 hours post-concussion generally indicates greater concussion severity and a longer return to play time (Tucker et al.). The presence of a mild TBI has been shown to be a good predictor of post-concussion symptoms one week after injury, but patient anxiety levels were the greatest predictor of having long-term (>3 months) concussion symptoms post-injury (Ponsford et al., 2012).

Limitations

There were several limiting factors observed in this study. This study only tested visuomotor RT and did not include somatosensory reaction tests. Pearce et al. (2020) found that although there were no significant differences in visuomotor RT between a concussion group and control group, there was significant RT slowing and increased variability in the concussion group when completing somatosensory reaction tests.

The participants were recruited indirectly through their respective coaching staffs. Teams with coaches who did not allow researchers to test athletes at their practice facilities saw very low participation in the study, reducing the sample size. Having a small sample size also reduces the power of the results and potentially increased the chances for additional Type II errors.

The physical environments used were the practice facilities of each respective sports team. This made environmental controls challenging as athletes being tested were unable to be sequestered from their teammates. This resulted in many athletes watching and encouraging their teammates who were being tested which may have impacted subject performance. Some athletes who finished testing early spoke to teammates who had not yet completed testing and informed them of their experiences while providing tips for success. As multiple testers administered both the ruler drop test and trail making tests, inter-rater reliability becomes a potential concern, especially in those tests requiring the use of a stop watch at the start and end of the tests.

The light reaction board was designed by the PI and was a novel design composed of eight sensors arranged in a pattern of a diamond inside a larger rectangle: Four sensors were arranged at each corner of the light board and the other four sensors were arranged in a diamond pattern inside of the boarders of the four corners. With having a novel test design, we are limited in our data interpretation as we have created a segment of the testing battery without normative data. Additionally, the light sensors required participants to physically touch the sensors for the target to be recorded as a valid touch. This led to some participants having issues with touching the sensors too softly and not eliciting a response from the sensor, or hitting the sensors with extreme force causing the entire light board to vibrate and shake, which would make additional sensors trigger as being touched due to the immense shock to the board. While most of this was mitigated by having participants complete a practice trial before the actual test, it did result in needing to have participants have to reset the light reaction board several times during testing due to participants striking the board too forcefully.

Future Research

Future research should continue to expand on our knowledge of appropriate return to play protocols for athletes recovering from acute concussion, as well as recognition and appropriate action to limit participation in student-athletes experiencing ongoing concussion symptoms after their projected recovery time has completed. Lempke et al. (2023) suggest using a single task and dual task testing system, where athletes would be subjected to several performance tests as a single-task measure, and then testing under different cognitive states (either single task or a dual task state where athletes would perform basic math problems concurrently with the physical task). Additionally, Cole et al. (2021) found that the use of somatosensory-based testing of RT and RT variability was able to discriminate between healthy service members and those with an acute concussion better than visuomotor testing alone.

Honda et al. (2018) have suggested implementing vision training and neck musculature strength training as a preventative measure to potentially lessen the severity of head trauma by helping athletes to protect and anticipate head impact during activity. Using visuomotor and somatosensory training could prove to be beneficial in preventative care and maintenance of healthy and post-concussion athletes. This could also open the possibility for research and concussion management strategies that extend to support the education and prevention of occupational health risks.

As movement confidence may impact movement competence post-concussion, it may be beneficial to incorporate tests of movement confidence involving RT to better gauge readiness to play. Reinking et al. (2021) indicated that fear of pain with movement, or kinesiophobia, was much more prevalent in post-concussion athletes compared to a control population. Previous research has indicated that functional RT (i.e., movements or activities that correlate to movements or activities seen in sport, such as a single-leg hop or gait analysis) does not correlate with RT and should be assessed separately prior to an athlete returning to play (Lempke et al., 2020).

Additional longitudinal studies should be undertaken to determine the long-term implications of concussion management in individuals without suspected CTE or cognitive impairments. Speaking from the perspective of occupational health, Mandlowitz (2019) suggested that organizations should partner with local neuropsychological medical providers to independently assess concussed employees with the ultimate goal of having a safe return to work.

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