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RESEARCH ARTICLE

Knockouts are Accompanied by an Immediate Loss of Muscle Tone

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ABSTRACT
We analyzed videos of boxing matches and mixed-martial-arts fights. We observed an immediate and severe loss of muscle tone following a knockout. This impact-induced loss of muscle tone was typically transient, lasting seconds or less. This phenomenon involved muscles in the upper and lower limbs, and possibly axial muscles as well as the facial musculature. The observation is best described as an active person instantaneously transformed into an inanimate object, followed by a free fall in gravity accompanied by flaccidity or paralysis. Analyzing double-knockouts, we concluded that the observed impact-induced loss of muscle tone occurred within tens of milliseconds of a head hit. The speed, scope, and severity of the muscle tone loss are not consistent with a local loss-of-function mechanism. Because such loss of muscle tone closely resembles sudden attacks in cataplexy patients, we hypothesized that severe head impacts may directly involve brain centers that regulate rapid eye movement sleep. These brain centers may be part of an active mechanism to shut down the muscle tone quickly and globally. When muscle tone is low or absent, athletes are at elevated risk for further injuries in combat or contact sports. Athletes, athletic trainers, and referees in combat as well as contact sports should be vigilant and recognize signs of impact-induced loss of muscle tone in order to improve player safety and better protect these athletes.

Introduction

Concussions, or mild traumatic brain injuries (mTBI), carry significant risks in participants of contact sports such as American football, soccer, and hockey.[1,2] In team contact sports, clinicians and athletic trainers routinely make sideline diagnoses based on established signs and symptoms of concussions.[2-5] The list of symptoms includes dizziness, nausea, vomiting, cognitive confusion, blurred or double vision, slurred speech, and balance deficits with or without loss of consciousness.[3,5] For American football players or soccer players as well as many other contact team sports, concussion protocols lasting a week or more are becoming mandatory before return-to-play decisions.

Combat sports such as boxing, wrestling, and mixed-martial-arts (MMA) competitions also carry a significant risk of concussion.[6,7] Referees in combat sports are trained to stop the competition to prevent severe and life-threatening injuries to the combatants. The most critical component of the rules for stopping the fight on a knockout (KO) or technical knockout (TKO) decision is the ability of a fighter to defend himself or herself.[8-11] Indeed, on the Type of Decisions from the Unified rules of mixed martial arts approved by the Association of Boxing Commissions and Combative Sports, the language is that the referee should stop the contest "because the combatant is not intelligently defending himself/herself."

Muscle tone, or the lack of it, has not occupied a prominent position on the list of symptoms for clinical and sideline diagnosis of concussions.[2-5] Neither is muscle tone explicitly mentioned in the guidelines for referees in boxing or MMA fights.[8-11] The objective of this study is to systematically describe a characteristic loss of muscle tone immediately following KOs. We analyzed videos of boxing matches and MMA fights. Our data indicated that the muscle tone immediately after an KO hit can be absent, can affect the entire skeletomuscular system, and can appear quickly, and disappear just as quickly (e.g., in seconds or sometimes less than a second). When muscle tone is low or absent, an athlete is at elevated risk for further injuries in combat or contact sports. Knowledge on the properties of impact-induced loss of muscle tone (ILoMT) is relevant as it may help drive the development of technology to better protect the athletes in contact and combat sports and to prevent severe injuries. In addition, such information may also provide clues to potential neurobiological mechanisms for the manifestation of ILoMT and of concussions in general.

Methods

Source of Videos

We analyzed videos of boxing matches and MMA fights. The videos were identified after searching with keywords including knockout, KO, boxing, and MMA (Table 1). Many of the videos chosen for analysis were filmed in the last two to three years. The graphic quality of the videos is generally excellent for our purpose, and many of the videos include views from several different angles.

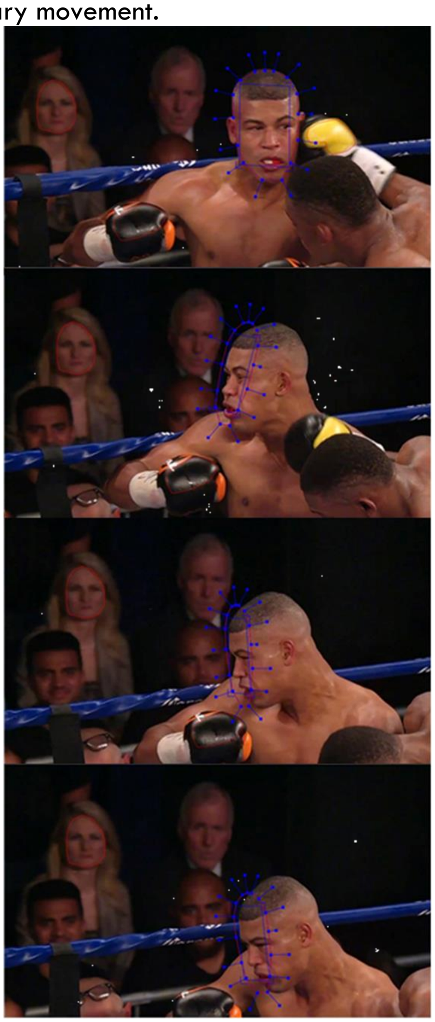
Name of Video	Link
Top 60 UFC Knockouts of All Time	https://www.youtube.com/watch?v=Pc2el7kijVg
Best UFC Knockouts	https://www.youtube.com/watch?v=Bkd2-QcBI_o
Best UFC KOs 2021	https://www.youtube.com/watch?v=x7QUEUT4CXg
Boxing's Top 25 Knockouts Of 2020	https://www.youtube.com/watch?v=A8z56Myzuyo
Body Shot Knockouts That Destroyed Fighters	https://www.youtube.com/watch?v=HT1wBOdlYos

Table 1. Sources of YouTube Videos.

Video Analysis Protocols

We focused on the manifestation of ILoMT in the final, decisive KO hit of a given match. Examinations were made by playing the video back at 25% of the original film rate and frame-by-frame if necessary. In this manner and for each KO case, we collected the relevant data inferring the muscle tone of the stricken fighter over the critical video frames spanning a period of several seconds immediately before and after the hit. For example, Figure 1 contains four frames of a YouTube video (33 msec in-between frames) showing a typical KO head hit causing a transient loss of muscle tone in the lower limbs. As the muscle tone in the lower limbs disappeared, the entire body mass of the fighter sank in the presence of gravity. In Figure 1, using the stationary spectators in the audience and the rope of the ring as references, one can readily conclude that the top of the head of the stricken fighter sank significantly from frame 1 to frame 4 within a time span of 100 msec. Considering that the average length of an eye blink is 300-400 msec, the speed of ILoMT is fast, suggesting that ILoMT occurs with a speed rivaling or faster than the speed of a typical voluntary movement.[12]

Figure 1. *Four frames of a YouTube video (33 msec in-between frames) showing a typical KO head hit causing a transient loss of muscle tone in the lower limbs.* Spline markers placed on the face of the boxer by a video processing software facilitate the tracking of the position of the face and the head. Using the stationary spectators in the audience and the rope of the ring as references, one can readily conclude that the top of the head of the stricken fighter sank significantly from frame 1 to frame 4 within a time span of 100 msec. Considering that the average length of an eye blink is 300-400 msec, this observation suggests that impact-induced loss of muscle tone (ILoMT) occurs with a speed rivaling or faster than the speed of a typical voluntary movement.



In our analysis, we focused on whether there was a near-absence of muscle tone in the lower limbs by looking for signs of a free fall of the body to the ground. We also documented whether the stricken fighter still had the use or motor control of his lower limbs as evidence of the fighter reflexively taking steps in order to avoid falls. On the muscle tone and reflexes of the upper limbs, we documented signs of purposeful movements, such as attempting to move and mobilize the upper limbs to break a fall. The video analysis was conducted by CH and RH. Results were compared, discussed, reconciled, compiled, and tabulated.

Results

General features of impact-induced loss of muscle tone

Athletes in combat sports are trained to efficiently deliver hits to the opponent's head by the fist, the elbow, the feet, and the knee, all of which occurred in our data sample. During a typical fight, the athletes fight on under the referee's watchful eyes while delivering and receiving hundreds of such hits. Most of these head hits do not appear to degrade immediately and significantly the ability of the fighters to continue. However, that is not the case for the one final KO blow. A KO hit is always accompanied by a clear manifestation of ILoMT, which is *transient*. Nonetheless, the muscle tone in those fleeting moments right after the hit can be *absent altogether*. This ILoMT can seemingly affect the *entire skeletomuscular system* from head to toe.

While the main functions of the motor system are broadly divided into postural balance and movement, ILoMT affects *both*. First, the stricken fighter immediately becomes unable to maintain an upright posture under normal gravity and is often seen to execute a free fall toward the ground. Second, there is no evidence of any movement execution in the immediate moments after ILoMT. Afterwards, while still on the ground as the transient ILoMT subsides, the stricken fighter typically appears to be dazed, unfocused mentally, and weak or unable to move physically. At this time, the referee often stops the fight as the stricken fighter is clearly in no position to defend himself or herself while facing an aggressive opponent who is eager to further take advantage of a defenseless opponent.

In Figure 1, the positions of the top of the head of the stricken fighter became lower from frame 1 to frame 4 within a time span of 100 msec. Continuing the fall, the stricken fighters in all of the cases in the present study were on the ground, typically within one second or less. We abandoned an attempt to derive more precise information on the timing of the falls as the falls took all forms (front, back, or sideways). In addition, the film rate (frames per second) of YouTube video is typically too slow and not ideal for the extraction of precise timing data.

Under normal gravity, the splat time in free fall can be calculated from Newtonian mechanics to be ~450 msec for the buttocks (at 1 meter) and ~640 msec for the head (at two meters). The observed time course of the falls in our videos is therefore consistent with that calculated for an object executing free fall in gravity. This observation therefore suggests a near-total loss of muscle tone in the lower limbs.

Table 2 shows a total of 153 cases (147 male and 6 female) taken from three compilations of videos on MMA fights and one compilation of videos on boxing matches. There were 134 cases (out of 153 cases, 87.6%) in which the stricken fighter experienced a single head blow, after which the resultant ILoMT transiently caused a near-absence of muscle tone. This was accompanied by a free fall to the ground. In 19 cases (out of 153 cases, 12.4%) in which the stricken fighter was first taken down by various techniques in wrestling or means other than a clear-cut single hit and subsequently overpowered and rendered defenseless. We also included in these 19 cases in which the free fall of the fighter was impeded by any object, including the referee or the fence of the cage. The delineation of these 19 cases from a total of 153 cases were necessary, in our view, because we could not clearly discern that the TKO or KO were attributable to a single head hit or because we could not clearly establish the free fall in gravity due to the stricken fighter was braced and thus interfered by the fence. It is clear, however, that the percentage of the free fall after a KO head hit would be higher than 87.6%.

	Number	**Free Fall**	**No Free Fall**	**Upper Limb Use**
Top 60 UFC KO All Time	61	54	7	8 of 54
Best UFC Knockouts	18	16	2	4 of 16
Best UFC KOs 2021	45	38	7	12 of 38
Boxing's Top 25 KO 2020	29	26	3	2 of 26
Total	153	134	19	26 of 134
Percentage	**100**	**0.876**	**0.124**	

Table 2. Summary of MMA and Boxing Data on the presence or absence of free falls and on the use of upper limbs.

<u>Muscle tone of the limbs</u>

In 134 out of 153 cases (87.6%) of Table 2, the immediate, transient ILoMT involved both lower limbs. As the muscle tone in the lower limbs disappeared, the entire body mass of the fighter fell. Among these 134 cases, there was *one* case in which the stricken fighter was observed to reflexively make a step with one of the lower limbs but was ultimately unsuccessful in preventing the fall. In the other 133 cases, no lower limb movement was evident after the hit and during the free fall. However, in 26 of the 134 cases (19.4%), the stricken fighters were observed to apparently brace the free fall with one or both of the upper limbs. In these 26 cases, the muscle tone in the upper limbs may have made a partial recovery before the end of splat time, suggesting that the recovery from ILoMT is also quite fast, probably and typically within one second.

These 153 cases included 29 cases of KOs in boxing matches (not MMA fights). In 26 out of these 29 cases, we observed a near-absence of muscle tone in the lower limbs (89.7%) and in 2 of 26 cases (7.7%) we observed the use of upper limbs to brace the falls. In addition, in 3 of the 29 cases, the KOs were due to a punch to the rib cage and did not result in a free fall to the ground. The data on the percentage of absence of muscle tone in both upper and lower limbs was therefore largely consistent in the boxing data and in the MMA data.

Beyond these 153 cases, we examined 10 KO cases in boxing matches in which the KO punch was delivered to the body rather than the head. In these 10 cases, the fighters also fell to the ground, but the falls typically took 2-3 seconds and were never free falls in gravity. Moreover, all the falls after a KO hit the body were executed without loss of balance. The stricken fighter almost always made steps to keep their postural balance and sometimes braced with upper limbs as the body lowered to the ground. A second finding is that the stricken fighter all made clear facial expressions signaling the pain from the body hit. By contrast, no facial expressions were observed in any of the KO hits.

Other muscles

We suspected that there was ILoMT in the torso muscles as well. No systematic examinations were made on trunk musculatures in the present study as signs of torso muscle tone loss are more subtle than those signs on limb muscles and therefore more difficult to detect, document, and measure in these videos within the time span of a second. Impact-induced loss of muscle tones in axial musculature can be seen more clearly when an airborne athlete hits the ground as in football players.[13] For example, a falling football player can often be seen to fall "limp" as if superficial, deep, and intrinsic back muscles are all without tone.

In our observations, a boxer almost always grimaced as he fell after a painful blow to the body, particularly when the hit involved the lower part of the rib cage. By contrast, grimacing or any form of facial expression was *never* observed after a hit to the head in all the cases examined in the present study. A hit to the head may not be as painful as a hit to the ribcage, but it is more likely that the KO occurred too quickly for the fighter to make any facial expression or that the facial musculature may have also lost its muscle tone.

The speed of the onset of impact-induced loss of muscle tone

We also obtained information on how quickly ILoMT can occur after a head hit. As mentioned above, the speed of ILoMT is fast. This introduces difficulties in precisely and directly determining the speed or timing of ILoMT since the videos are filmed at a speed not ideally suited for this purpose. We, therefore, resorted to double KO incidents (DKO) in which the two fighters knocked out each other (Figure 2). DKO events are rare but occur with regularity.[14] The rationale for studying DKO is that once a fighter is knocked out, the loss of muscle tone will make it impossible to knock out his opponent. Therefore, the two critical punches in DKO must occur nearly simultaneously with the slight delay between the two final punches giving us a measure of how fast the loss of muscle tone in KOs could take effect. Table 3 shows that the two punches occurred in the same video frame (13 out of 20 cases) or adjacent frames (7 out of 20 cases). Given that the videos are filmed at 30 frames per second, the time span of each video frame is 33.3 msec. Assuming that the two punches occur randomly in time during these fleeting moments, then in 13 cases in which the average time interval between the two punches is estimated as [(1/4) x 33.3 = 8.3 msec].

Figure 2. *Double knockout hits (DKO)*. Two boxers can knock out each other if the two KO hits are landed almost at the same time. In truth, one hit lands slightly before the second one. The delay between two KO hits in DKO cannot be longer than the time it takes for a KO punch to produce the loss of muscle tone.

In the 7 cases in which the two punches occur in adjacent frames, the average time interval between the two punches is estimated as [33 msec]. We derive the time constant according to [(8.3 x (13/20)] + [(33 x (7/20)] = 16.95 msec. Our interpretation is that if a fighter is hit and a KO is in progress, the ILoMT will take over the motor system of the fighter within ~17 msec, a period during which the stricken fighter will have no muscle tone and therefore zero chance to knock out his opponent. However, if the two hits land on two heads within 17 msec and before the muscle tone can disappear, a DKO is possible.

Videos	Frame
Thomas Hearns vs Jay Snyder	a
Schiller Hypolite vs Darnell Boone	s
Darrell Provo vs Raphael Butler	s
Sechew Powell vs Cornelius Brundage	s
Kerwin Sherrill vs Derek Thompson	s
Rob Emerson vs Gray Maynard	s
Diogo Nieves vs Eder Lopes	s
Matt Mitrione vs Fedor Emelianenko	s
Tyler Stinson vs Rob Kimmons	s
Jay Jackson vs Owen Martin	a
Shawn Parker vs Tyler Bryan	s
Alan Vasquez vs Axel Cazares	s
Irosvani Duvergel vs Jerhed Fenderson	a
Corey Champion vs Peter Cortez	a
Brandon Alexander vs Aaron Britt	s
Marcin Mencel vs Mateusz Zawad	a
Dorian Price vs Jonathan Lecat	s
Lee Roy Murphy vs Chisanda Mutti	s
Cello Renda vs Paul Samuels	a
Billy 'Bang Bang' Hawthorn vs Nathen Jdogg	a

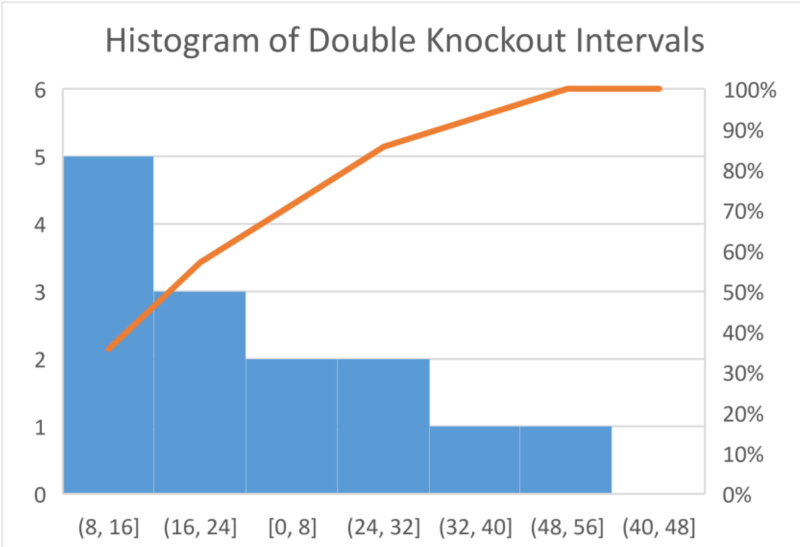
Table 3. Double KO hits in the same or adjacent video frames. s: KO hits in same video frame; a: KO hits in adjacent video frames.

As an alternative way to identify the speed of ILoMT, we also engaged in frame-by-frame video analysis in which we attempted to create manually sketched "in-between" pictures of the hitting fists as well as the heads as targets. By this interpolation process, Figure 3 shows the histogram of the time interval between the two punches in DKO. The data indicated that the range of time lag between the DKO punches was 0-50 msec with the mean time lag between the two DKO punches being 18.6±14.6 msec. While our manual interpolation process undoubtedly introduced human errors, we took comfort in the fact that not only the two alternative estimates are consistent with each other but also that Figure 3 takes the form of a Poisson distribution, in which the standard deviation of the data equals the mean of the data. A Poisson distribution is also entirely consistent with the mathematical description of the two punches in DKO as discrete and random events.

The duration of impact-induced loss of muscle tone

We also estimated the duration of the ILoMT based on the observations in the present study. First, we have observed a partial recovery of the use of upper limbs before the end of the splat time in a fraction of the stricken fighters. Thus, by the time the buttock of the fighter is on the ground (~450 msec), 7.7 (from boxing) to 19.4% (from MMA fights) of the fighters were able to move their upper limbs to brace the fall effectively. Our interpretation is that the average duration of severe muscle tone loss and the loss of use of upper limbs should be sufficiently brief that between 7.7 to 19.4% of the fighters were able to regain at least partial function of the upper limbs within ~450 msec of the hit. At present, there is no information on whether the recovery process is linear with respect to time, which prevented a more detailed estimation of the recovery from ILoMT. In addition, the duration of ILoMT may be highly dependent upon the magnitude of the force involved in the hit, a parameter that is not controlled in the present study. For these reasons, we do not have more definitive information on how long it takes for muscle tone to return to control level from ILoMT. Given that the splat time for the buttock and the head are ~450 and 640 msec respectively, the duration of ILoMT is at least in that time range.

Figure 3. *Histogram of Double Knockout (DKO) intervals.* Y axis on the left is frequency. X axis is msec. The line refers to the cumulative count (Y axis on the right). The histogram takes the form of a Poisson distribution, in which the standard deviation of the data equals the mean of the data. A Poisson distribution is also consistent with the mathematical description of the two punches in DKO as discrete and random events.



Discussion

<u>Summary and the limitation of the study</u>

A transient ILoMT occurs in KOs. The loss of muscle tone can be nearly complete. The duration of ILoMT is, however, brief and typically lasts only seconds or less. The phenomenon can best be described as an active person transformed into an inanimate object, followed by a free fall in gravity accompanied by flaccidity or near-paralysis in all skeletal musculatures. The upper and lower limbs of the fallen fighter may assume "unnatural" positions, reinforcing the immediate cessation of all motor activities following the head-impact. Although the duration of ILoMT is brief, fighters without muscle tone will not be able to defend themselves and can sustain serious and yet avoidable injuries in a combat sport.

We had no control over many parameters in the present preliminary study, including the magnitude and the direction of the impact force of the impact force as well as the precise contact point on the head being struck. We also had no control over the distance between the camera and the fighter or the camera's angle. The film rate in YouTube videos is too slow to determine the precise timing information. Although the sample of cases may appear to be random, the size of the dataset may be too small to be truly representative. At another level, we also cannot equate KOs with concussions or mTBI. Therefore, the complex relationship between ILoMT, KOs, and concussions awaits further studies with better source data, e.g., high-speed and high-resolution videos, EMG (electromyogram) recordings from athletes, clinical studies, as well as better analysis tools. Nevertheless, results of the present study should be sufficient to bring the subject matter of ILoMT to the foreground of sports safety. In particular, ILoMT may be a worthy biomarker linking KOs to concussions.

<u>The role of muscle tone in contact sport and implications for sports safety</u>

At present, many States in the US have established concussion protocols for athletes at the high school, college, and professional levels. For example, if a football player is suspected of experiencing a concussive event, he must not return to play before completing a mandatory concussion protocol, typically a five-step procedure that takes a week.[5,15] Similar protocols also govern the return-to-fight decisions for athletes of combat sports.[8,9]

A boxer that experienced a head hit during a fight and exhibited signs of ILoMT prior to the KO or TKO declaration by the referee is technically a knockdown. The current set of rules and conventions on knockdowns *allow* fighters to return to fight as long as they can beat the "long count" (typically in about ten seconds) and consent to continue. At present, a knockout is not universally considered as a concussive event and a knockdown is not automatically acknowledged as a potential concussive event. For example, according to the website and the most recent consensus statement from the Association of Ringside Physicians, "concussion can certainly accompany a TKO, but a TKO does not always have to be associated with a concussion ….., concussion can still occur even if there is no KO or TKO."[10,16] We believe that, in contact sports such as football or hockey and in combat sports such as boxing or MMA fights, signs such as transient muscle tone loss during a game or a competition should be universally recognized as a potential concussion, particularly in considering whether an athlete can continue to compete or fight in that game or competition. It may be time to reconsider the long count in combat sports.

Neural mechanisms of impact-induced loss of muscle tone

The loss of muscle tone in KO events can be severe or nearly complete. The scope, severity of the muscle tone loss, and the under-twenty-millisecond speed in ILoMT are inconsistent with a local loss-of-function mechanism. However, they are congruent with an active mechanism mediated by the central nervous system to shut down the muscle tone globally and quickly. Remarkably, similar scope and speed in the loss of muscle tone can be seen during REM sleep (rapid eye movement).[17] REM sleep, however, does not always involve a complete loss of muscle tone as many mammal species sleep while standing and must continue to retain sufficient postural control against gravity. From an evolution perspective, loss of muscle tone after an impact event can be observed in the fly animal model,[18] which is also a popular animal model in sleep studies.[19] Despite the long evolutionary history in the animal kingdom, it is not clear how ILoMT enhances the fitness of a species. The relationship between ILoMT and sleep mechanisms is still poorly understood at present.

Implications for concussion diagnosis

At present, clinicians and athletic trainers routinely make sideline diagnoses based on established signs and symptoms of concussions.[1-5] The list of symptoms includes dizziness, nausea, vomiting, cognitive confusion, blurred or double vision, slurred speech, and balance deficits with or without loss of consciousness. The list of symptoms has been increasingly exploited in commercial apps, including SCAT5, IMPACT, VOMS, and others.[20-22] However, the goal of definitive identification of sports-related concussions remains elusive.[23-28]

In addition, the high-tech industry has developed MEMS (Microelectromechanical Systems) head-impact sensors with the capability to monitor head kinematics and shed light on the severity of the impact.[29-30] The goal of such accelerometer- or IMU-based (Inertia measurement unit) technology was to provide objective and quantitative information of clinical utility to aid the diagnosis of concussions. However, many investigators concluded that modern MEMS technology categorically failed to detect concussions and had limited clinical utility due to low sensitivity and specificity.[30] An EMG-based sensor for ILoMT should be feasible. In addition to machine learning algorithms to spot injuries in video analysis for the protection of athletes in combat sports[31], it should be beneficial to introduce a wearable EMG-based TBI sensor to aid objective concussion assessment in real-time.

Conclusion

We observed an immediate and severe loss of muscle tone following a KO. This impact-induced loss of muscle tone was typically transient, lasting seconds or less. The loss of muscle tone involved muscles in the upper and lower limbs, and possibly axial muscles as well as the facial musculature. There are two takeaway messages. First, when muscle tone is low or absent, an athlete is at elevated risk for further injuries in combat or contact sports. Athletes, athletic trainers, and referees in combat as well as contact sports should therefore be vigilant and recognize signs of impact-induced loss of muscle tone in order to improve player safety and better protect these athletes. Second, monitoring EMG to detect ILoMT may be a promising technological approach for the identification of potential concussive events.

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References Cited

1. Ianof JN, Freire FR, Calado VTG, et al. Sport-related concussions. Dementia & Neuropsychologia. 2014;8(1):14-19. doi:https://doi.org/10.1590/s1980-57642014dn81000003
2. Broglio SP, Cantu RC, Gioia GA et al. National Athletic Trainers' Association Position Statement: Management of Sport Concussion. Journal of Athletic Training. 2014;49(2):245-265. doi:https://doi.org/10.4085/1062-6050-49.1.07
3. Mayo Clinic. Concussion - Symptoms and causes. Mayo Clinic. Published 2017. https://www.mayoclinic.org/diseases-conditions/concussion/symptoms-causes/syc-20355594
4. Putukian M. Clinical Evaluation of the Concussed Athlete: A View From the Sideline. Journal of Athletic Training. 2017;52(3):236-244. doi: https://doi.org/10.4085/1062-6050-52.1.08
5. Centers for Disease Control and Prevention. Sports Concussion Policies and Laws. Published 2019. https://www.cdc.gov/headsup/policy/index.html
6. Curran-Sills G, Abedin T. Risk factors associated with injury and concussion in sanctioned amateur and professional mixed martial arts bouts in Calgary, Alberta. BMJ Open Sport & Exercise Medicine. 2018;4(1):e000348. doi: https://doi.org/10.1136/bmjsem-2018-000348
7. Hutchison MG, Lawrence DW, Cusimano MD, Schweizer TA. Head Trauma in Mixed Martial Arts. The American Journal of Sports Medicine. 2014;42(6):1352-1358. doi: https://doi.org/10.1177/0363546514526151
8. Association of Boxing Commissions and Combative Sports Unified Rules of Mixed Martial Arts. https://www.dli.mn.gov/sites/default/files/pdf/official_unified_rules_MMA.pdf
9. Rulebook. Team USA. Published 2022. https://www.teamusa.org/usa-boxing/rulebook/
10. Neidecker J, Sethi NK, Taylor R, et al. Concussion management in combat sports: consensus statement from the Association of Ringside Physicians. British Journal of Sports Medicine. Published online July 26, 2018:bjsports-2017-098799. doi: https://doi.org/10.1136/bjsports-2017-098799
11. Sports-Related Concussions in Youth. National Academies Press; 2014. doi: https://doi.org/10.17226/18377
12. Adler FH. Adler's Physiology of the Eye: Clinical Application. C. V. Mosby Company; 1975. (pp 1-15) Accessed May 2, 2023. https://books.google.com/books/about/Adler_s_Physiology_of_the_Eye.html?id=T4ZsAAAAMAAJ
13. NFL Biggest Knockout Hits Ever (Brutal Hits). YouTube. Published online October 29, 2017. Accessed January 14, 2020. https://www.youtube.com/watch?v=LJSNhG7xoyk
14. Vladisavljevic V. Boxing VS MMA: Difference Between KO And TKO And How To Win. Accessed May 2, 2023. https://wayofmartialarts.com/difference-between-ko-and-tko-in-boxing-and-mma/
15. NFL Return-To-Participation Protocol. NFL.com. https://www.nfl.com/playerhealthandsafety/resources/fact-sheets/nfl-return-to-participation-protocol
16. Association of Ringside Physicians, Published 2023, https://ringsidearp.org/consensus-statements/
17. Arrigoni E, Chen MC, Fuller PM. The anatomical, cellular and synaptic basis of motor atonia during rapid eye movement sleep. The Journal of Physiology. 2016;594(19):5391-5414. doi: https://doi.org/10.1113/jp271324
18. Li D, Li F, Guttipatti P, Song Y. A Drosophila In Vivo Injury Model for Studying Neuroregeneration in the Peripheral and Central Nervous System. Journal of Visualized Experiments. 2018;(135). doi: https://doi.org/10.3791/57557
19. Cirelli C, Bushey D. Sleep and wakefulness in Drosophila melanogaster. Annals of the New York Academy of Sciences. 2008;1129:323-329. doi: https://doi.org/10.1196/annals.1417.017
20. Sport concussion assessment tool - 5th edition. British Journal of Sports Medicine. Published online April 26, 2017:bjsports-2017-097506SCAT5. doi: https://doi.org/10.1136/bjsports-2017-097506scat5
21. ImPACT Concussion Test | ImPACT Applications. impactconcussion.com. Published 2017. https://impactconcussion.com/
22. Assessment and Management of Concussion. Physiopedia. Accessed May 2, 2023.

https://www.physio-pedia.com/Assessment_and_Management_of_Concussion

23. Davis GA, Makdissi M, Bloomfield P, et al. International study of video review of concussion in professional sports. British Journal of Sports Medicine. 2018;53(20):1299-1304. doi: https://doi.org/10.1136/bjsports-2018-099727
24. Gardner AJ, Kohler R, McDonald W, Fuller GW, Tucker R, Makdissi M. The Use of Sideline Video Review to Facilitate Management Decisions Following Head Trauma in Super Rugby. Sports Medicine - Open. 2018;4(1). doi: https://doi.org/10.1186/s40798-018-0133-4
25. Gardner AJ, Howell DR, Levi CR, Iverson GL. Evidence of Concussion Signs in National Rugby League Match Play: a Video Review and Validation Study. Sports Medicine - Open. 2017;3(1). doi: https://doi.org/10.1186/s40798-017-0097-9
26. Makdissi M, Davis G. The reliability and validity of video analysis for the assessment of the clinical signs of concussion in Australian football. Journal of Science and Medicine in Sport. 2016;19(10):859-863. doi: https://doi.org/10.1016/j.jsams.2016.02.015
27. Hutchison MG, Comper P, Meeuwisse WH, Echemendia RJ. A systematic video analysis of National Hockey League (NHL) concussions, part I: who, when, where and what? British Journal of Sports Medicine. 2013;49(8):547-551. doi: https://doi.org/10.1136/bjsports-2013-092234
28. Echemendia RJ, Bruce JM, Meeuwisse W, Hutchison MG, Comper P, Aubry M. Can visible signs predict concussion diagnosis in the National Hockey League? British Journal of Sports Medicine. 2017;52(17):1149-1154. doi: https://doi.org/10.1136/bjsports-2016-097090
29. Duma SM, Rowson S. Every newton hertz: A macro to micro approach to investigating brain injury. International Conference of the IEEE Engineering in Medicine and Biology Society. Published online November 13, 2009. doi: https://doi.org/10.1109/iembs.2009.5333423
30. O'Connor KL, Rowson S, Duma SM, Broglio SP. Head-Impact–Measurement Devices: A Systematic Review. Journal of Athletic Training. 2017;52(3):206-227. doi: https://doi.org/10.4085/1062-6050.52.2.05
31. Yengo-Kahn A, Zuckerman SL. Letter: Preventable Deaths, Video Analysis, Artificial Intelligence, and the Future of Sport. Neurosurgery. 2019;86(3):E349-E350. doi: https://doi.org/10.1093/neuros/nyz452