Current Research: Concussion

Usability And Tolerability Of Novel Brain Injury Prevention Device Used In High School Football

--Manuscript Draft--

Manuscript Number:	
Full Title:	Usability And Tolerability Of Novel Brain Injury Prevention Device Used In High School Football
Article Type:	Original Study
Keywords:	Intracranial pressure, Altitude, Jugular compression, Concussion, mTBI, prevention
Corresponding Author:	Gregory D. Myer, Ph.D. UNITED STATES
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	
Corresponding Author's Secondary Institution:	
First Author:	Samuel D Roth
First Author Secondary Information:	
Order of Authors:	Samuel D Roth
	Guy Cohen
	Kim Barber Foss, MS
	Staci Thomas, MS
	Michael Gordon
	Ken Rushford
	David W Smith, MD
	Gregory D Myer, PhD
Order of Authors Secondary Information:	
Abstract:	Objective: According to the Center for Disease Control (CDC), an estimated 1.6 to 3.8 million mild traumatic brain injuries (mTBI) occur each year in the United States.Given the magnitude and potential long-term consequences of this injury, the focus on prevention of sports related traumatic brain injury (sTBI) is paramount. An innovative device, currently called the Q-Collar, was recently tested on high school football players. The purpose of the present study was to acquire participant feedback regarding their collar experience across a high school football season. Methods: A survey was created and distributed among the football participants. Results were received from 31 of the participating high school football players. The survey was composed of three categories of questions: collar effect on performance, collar use and experience, and collar care and storage. Results: Players (N=31) had an overall positive experience using the collar, feeling an increased sense of protection when wearing the device (0% negative responses), perceived improved performance and heightened maximum effort on the field (0% negative responses), and most athletes reported that they would continue to wear the device if made available in the future (6% negative responses). Players also reported little to no discomfort or pain while wearing the device. Conclusion: While this study did not investigate the effectiveness of the device in reducing mild TBI risk among high school football players, it showed that this device is both usable and tolerable among a small, selective sample of high school athletes.
Suggested Reviewers:	Walter Lowe

	University of Texas Medical School at Houston Walter.R.Lowe@uth.tmc.edu
Additional Information:	
Question	**Response**
Please enter the **Word Count** of your manuscript	3392

Usability And Tolerability Of Novel Brain Injury Prevention Device Used In High School Football

Samuel D Roth[1,2,3]
Guy Cohen[11]
Kim D. Barber Foss, MS ATC LAT[1,8,9]
Staci Thomas, MS[1]
Michael Gordon, BS[10]
Ken Rushford, BS[10]
David W. Smith, MD[1]
Gregory D. Myer, PhD[1,4,5,6,7]

AFFILIATIONS

[1]The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center, Cincinnati, OH.
[2]Science Research Department, Croton-Harmon High School, Croton on Hudson, NY.
[3]University of Pennsylvania, Philadelphia, PA.
[4]Department of Pediatrics, University of Cincinnati, College of Medicine, Cincinnati, OH.
[5]Department of Orthopaedics, University of Pennsylvania, Philadelphia, PA, USA
[6]The Micheli Center for Sports Injury Prevention, Waltham, Massachusetts.
[7]Department of Orthopaedic Surgery, University of Cincinnati, Cincinnati, Ohio
[8]Division of Health Sciences, Department of Athletic Training, Mount St. Joseph University, Cincinnati, Ohio
[9]Rocky Mountain University of Health Professions, Provo, UT
[10]St.Xavier High School, Cincinnati, OH.
[11]Columbia University, New York, NY.

CORRESPONDENCE

Name: Gregory Myer
Address: Cincinnati Children's Hospital
3333 Burnet Avenue; MLC 10001
Cincinnati, OH 45229
Telephone: 513-636-0249
Fax: 513-636-6374
Email: Greg.Myer@cchmc.org

ABSTRACT

Objective: According to the Center for Disease Control (CDC), an estimated 1.6 to 3.8 million mild traumatic brain injuries (mTBI) occur each year in the United States.Given the magnitude and potential long-term consequences of this injury, the focus on prevention of sports related traumatic brain injury (sTBI) is paramount. An innovative device, currently called the Q-Collar, was recently tested on high school football players. The purpose of the present study was to acquire participant feedback regarding their collar experience across a high school football season.

Methods: A survey was created and distributed among the football participants. Results were received from 31 of the participating high school football players to investigate their experiences when using the Q-Collar during the football season. The survey was completed as part of the athlete's post-season testing in conjunction with a larger study. The survey was composed of three categories of questions: collar effect on performance, collar use and experience, and collar care and storage.

Results: Players (N=31) had an overall positive experience using the collar, feeling an increased sense of protection when wearing the device (0% negative responses), perceived improved performance and heightened maximum effort on the field (0% negative responses), and most athletes reported that they would continue to wear the device if made available in the future (6% negative responses). Players also reported little to no discomfort or pain while wearing the device.

Conclusion: While this study did not investigate the effectiveness of the device in reducing mild TBI risk among high school football players, it showed that this device is both usable and tolerable among a small, selective sample of high school athletes.

Key Words: Intracranial pressure, Altitude, Jugular compression, Concussion, mTBI, prevention

INTRODUCTION

Over the past decade mild traumatic brain injuries (mTBI) has been portrayed as an epidemic among youth sport participation. mTBI complications have led to hundreds of millions of dollars in settlements in the past three years. The Center for Disease Control (CDC) estimates that 1.6 million to 3.8 million Americans suffer from sports related traumatic brain injuries (sTBI) each year, with 47% of sports related mTBI occurring in high school football[1]. Recent studies have found that such degenerative changes are more likely due to repetitive sub-concussive blows, the most notable complication being Chronic Traumatic Encephalopathy (CTE), a neurodegenerative disease caused by the buildup of tau-proteins in the brain.

Head protection has made incredible advancements since the beginning of human combat. The oldest known helmets were worn in the 23rd century BCE by the Akkadians and Sumerians, all the way through ancient Greek and Roman warfare near the time of 0 CE. Roman soldiers of the first century wore a Galea, a helmet that was typically made from bronze and adorned with horsehair that was meant to protect the head while also demonstrating dominance over an opponent. Materials changed as weaponry evolved through those eras, from leather and brass, to bronze and iron, protecting from arrows, cannons, and blunt force trauma. World War I brought on the need for stronger steel helmets, which helped to protect from bullets and shrapnel of trench warfare. Today's warfare helmets typically are made of Kevlar or other high tensile strength-to-weight material that mainly attempts to protect the skull and brain from damage in combat situations, from improvised explosive devices to bullets to grenades.[2]

Not only were the benefits of head protection needed in combat, but so too, in the athletic setting. Collision and contact sports have driven the desire to protect the skull and brain, stemming from a rash of at least 45 deaths from 1900-1905 of players in collegiate football.[3] The original helmet was designed to prevent skull fractures and subsequent brain hemorrhaging from occurring, and it worked to varying degrees. In 1969, the National Operating Committee on Standards for Athletic Equipment (NOCSAE) was formed to commission research directed toward head safety and injury reduction. The types of materials used in sports helmets have to meet a specific risk or need. The helmets are designed based on the type of collision sport, i.e. single impact helmets are likely made of frangible materials needing to be replaced after use.[4] Single impact helmets are typically used for cycling, rock climbing, and for on/off-road vehicles. Baseball, Hockey, Lacrosse, Cricket, and extreme sports all use a variation of a styrofoam (expanded polystyrene) absorption system inside the helmet, with a plastic shell on the outside protecting against skull fractures and superficial injuries. This shell allows the material to temporarily deform, but maintain shape, reducing the blow as much as possible. Evidence of prevention of concussions from any specific helmet is still difficult to find in the literature.[5,6]

Football helmets and cranial protection have similarly evolved from the leather helmets of the early 20th century, having not become mandatory protection until 1939 in the NCAA, and 1940 in the NFL.[7] Proposed protection progressed to plastic helmets in the 1940's, to adding facemasks and protective "padding" inside of the helmet, and then to placing an air bladder into the helmet in the early 1970's. The addition of chin straps helped to keep the helmet in place and improved the comfort of the experience, ultimately leading to a 4 point chin strap that was added in the mid 1970's to provide a more secure

fit. To further advancement in the protection of the head, NOCSAE developed a protective and standardized humanoid test for football helmets in 1973. Polycarbonate alloy was the next generation improvement in the 1980's and 1990's, making helmets lighter and more able to withstand collisions without breaking. As helmet companies kept comfort in mind, they used stronger but lighter materials for their protective devices. Next the turn of the century brought improvements that included protection to the mandible and an added lining of polyurethane and synthetic rubbers to go along with improved air padding inside the helmet, thus attempting to make the helmet more comfortable, but only with marginal success.[8] Many helmets have tried to reach the ultimate goal of a claim that they can reduce the impact, significance, and total number of concussive events, but haven't provided that in any literature to date.[9] Other studies have stated, and been discredited by outside research and the Federal Trade Commission, that their specific football helmet could reduce concussions by over 31%.[10] That reduction claim has been retracted by the helmet manufacturer after being subject to a Federal Trade Commission inquiry.

Young athletes have a greater head to neck size ratio, and among other reasons, concussions are more likely to occur in this age group.[11] Numerous measures have been taken to help reduce the number of concussions suffered by young athletes.[12] Many studies have been done on the biomechanics of concussion, trying to determine how most concussions occur, and the physical and physiological effects on the brain following mTBI, with the specific intent of presenting suggestions for effective prevention methods.[13,14] Mouth-based preventive devices have been tested, such as the Wipss® mouth guard, but have been shown to be no more effective than standard mouthguards in reducing mTBI.[15] Tom Farrey reported that the National Academy of Science showed that high school

football players suffered concussion rates of 11.2 concussions per 10,000 athletic exposures.[16] Despite all these decades and intensive attempts to alter this TBI plight, emergency room visits for concussion in kids ages 8 to 13 years old has doubled, and concussions have risen 200 percent among teens ages 14 to 19 in the last decade.[17]

Myer (2014) showed that 30% fewer Sport related Traumatic Brain Injuries (sTBI) occur among NFL players at an altitude above 644 feet, creating the idea of a high altitude physiological condition, simulated in sports, to help reduce mTBI.[18] The correlation between altitude and concussion rates is believed to be due to an increase in the intracranial volume due to the sparseness of available oxygen, allowing the brain to move around less within the skull, known as "slosh".[19] The Q-Collar device is designed based on a concept that mimics similar physiological responses to high altitude by slightly compressing the jugular vein, slowing blood flow from the brain, which mimics the blood volume of lying down, a perfectly safe physiological let alone neurological response.[20]

A survey of the involved athletes is necessary to understand their experiences with the Q-Collar. Regardless of how effective a device is in reducing concussion risk, players will not use the device if it is uncomfortable, or hinders athletic performance. Two primary goals of the survey are to understand how usable the device is for athletes, and to learn which aspects of the device cause discomfort, or how the device can be improved.

METHODS

Participants were recruited from a high school varsity football team and all enrolled participants/parents of participants were consented with IRB approved consent forms. Researchers at Cincinnati Children's Hospital explained how to properly wear and store the

Q-Collar prior to the season. Thirty-two players initially enrolled. Two players (6.25%) were not compliant with wearing the collar at all, two players (6.25%) were partially compliant, and the remaining twenty eight (87.5%) were fully compliant. One of the non-compliant participants did not complete the survey, resulting in a total of 31 survey responses. The collar study participants demonstrated an overall 88.7% total compliance (days of wear during impact practice or competition/days possible) of collar usage as prescribed by the study protocol.

During the 2015 St. Xavier High School Football season, the Q-Collars were worn by 32 athletes during every contact practice and game from July 20 through November 14, for a total of 74 days of practice and games. Starting in the middle of July with 2-a-day non-contact practices, the athletes wore the collars for acclimation during the heat of the summer with no shoulder pads worn and just helmets. Typically the 2-a-days practices lasted from 6:30 AM - 9:00 AM, and then again from 10:30 AM - 1:00 PM for a 5 hour total time worn. There were eight 2-a-day practices before August 1st (the first official day of football in Ohio), and then 7 days of 2-a-days until school started, which changed practices to the afternoon from typically 3:30 PM - 5:30 PM. Games usually would last from 7:00 PM - 9:30 PM, and they played a total of 2 preseason games, 10 regular season games, and 2 post-season games, for a total of 14 games.

The questions of this study's survey fit into 3 primary categories: collar use and experience, collar effect on performance, and collar care and storage, and were scored using an eleven point Likert Scale (-5 to -2 – negative response/no/infrequent, -1 to +1 – neutral response, +2 to +5 – positive response/yes/frequent). The full survey can be seen in the appendix.

The mean response, standard deviation, median response, upper and lower quartiles, as well as 95% confidence intervals for the means were all calculated. If the upper and lower confidence intervals showed the same sign (either both positive or both negative), a statistical conclusion could be made as to the population's overall experience with that specific aspect of usability and tolerability of the Q-Collar. If the upper confidence interval was positive and the lower confidence interval negative, the responses to that question were considered neutral, with no conclusive effect. The percentage of subjects who responded either positive, neutral, or negative to the questions were calculated. Negative/No was defined as a response of -5 to -2, neutral consisted of responses from -1 to +1, and Positive/Yes was responses from +2 to +5. For the freehand response question, qualitative analysis was performed, and responses were grouped into several categories based on suggested improvement. Based on the completed sample of 31 athletes, the margin-of-error is approximately +/-18%.

RESULTS

A sample of 31 football players from the selected high school, who wore the Q-Collar for the entire season, completed the survey. The average length of time in which the collar was worn (pre-season orientation date until post testing) was 129.7 +/- 14.9 days (range – 95-154) days, which also included post-season tournament play. The players were asked 23 questions, 21 of which used the -5 to +5 Likert scale, one multiple choice question pertaining to collar storage, and one freehand response regarding how to improve the collar.

Collar effect on performance (Tables 1 & 2): When asked about the collar's effect on tackling, there was no statistically significant improvement or hindrance reported by the players ($\bar{x}$=0.37, CI=(-0.09, 0.82)). The players reported similar results for the collar's effect on running ($\bar{x}$=0.30, CI=(-0.11, 0.71)). There was no significant change in players' perception on their ability to pass or receive the ball. When players were asked how wearing the collar affected their ability to give maximum effort on the field, there was a statistically significant response that players felt they were able to increase their ability to play at maximum effort when wearing the collar. None of the players reported a negative effect on play, 80.6% of players said there was no effect, and 19.4% reported a perceived increase in playing ability. Players reported feeling an overall increase in their blocking performance ($\bar{x}$=0.71 and CI=(0.15, 1.27)), with 19.4% of players reporting a positive change in ability, 80.6% reporting no change, and no players reporting negative change. When asked about whether or not the collar caused players to change their on-field technique, there was a statistically significant response that the collar did not cause them to change their technique ($\bar{x}$=-1.71, CI=(-2.71, -0.71)). 41.9% of players reported no change in technique, 51.6% had a neutral response, and only 6.5% reported changing their playing technique because of the collar.

Collar Use and Experience (Tables 3 & 4): When asked about the comfort of the collar, 29% of responses were unfavorable, 35.5% were neutral and 35.5% were positive. The mean response was 0.16 and median was -1.0. Players reported no difficulty in swallowing, as 48.4% of players reported a neutral response, and 35.5% gave a positive response ($\bar{x}$=1.10, CI=(0.11, 2.23)), indicating that swallowing was easy. There was no significant impact on breathing ability reported by the players. Players reported no negative change in

talking ability, as 54.8% of players responded between 2 and 5, and the median response was 3. Players also reported no negative effect on mental clarity, with a median response of 4, and 61.3% of players reporting between 2 and 5. There was no significant response by players as to the movement of the collar, as 41.9% of players reported frequent movement, 19.4% of players had a neutral response, and 38.7% reported little to no movement. The players reported no effect on hearing from using the collar, as 87.1% of responses were between -1 and 1. Players reported an overall increased feeling of protection on the field when using the collar, with a mean response of 2.06, and a median of 3. 45.2% of players reported a neutral effect on feeling of protection, while the remaining 54.8% of players all reported an increased feeling of protection when wearing the collar. There was a positive response when players were asked about their overall experience with the collar, with a mean of 2.97 and median of 3, and 77.4% of players reporting a positive experience (2 to 5). When asked whether or not they would continue to wear the collar, the overall response was positive. 77.4% would continue wearing the collar, 16.1% had a neutral response, and only 6.5% of players reported that they would not continue to wear the collar.

Collar care and storage (Tables 5 & 6): There was no significant response when players were asked whether or not they removed the collar when not on the field of play, as 45.2% of players reported taking it off frequently, 9.7% reported a neutral response, and 45.2% of players reported taking the collar off very rarely. Players reported an overall infrequency of taking the collar off between quarters ($\bar{x}$=-2.48, CI=(-3.70, -1.27)), as 64.5% of players reported infrequently removing the collar between quarters, and the median response was -5. Players reported a statistically significant positive response when asked if they forgot the collar was on, as 80.6% of players reported frequently forgetting that the collar was on

when playing. When asked how often the players washed the collar, there was a significant response of infrequency, as 61.3% of players reported infrequent collar washing, and the mean response was -2.03.

Free Response Question: The final question of the survey asked subjects what they would do to improve the collar. 11 players (35.4%) suggested no changes to the collar. 11 players (35.4%) suggested reducing the overall movement of the collar, mostly through an increased inner grip, or tighter overall fit. 3 players (9.6%) suggested a looser fit of the collar for more comfort, while 5 players (16.1%) suggested more padding on the inside of the collar to increase comfort.

DISCUSSION

Both primary goals of understanding player experience with the Q-Collar, as well as suggested improvements of the collar were addressed in the survey. The majority of players had a very positive experience using the Q-Collar, and would continue to wear the Q-Collar in future athletic competitions. Surveys have been distributed in the past regarding concussion knowledge and awareness and have found that coaches and players are both often unaware of the dangers of concussion, presenting the need for better sTBI education to go along with sTBI reduction methods.[21,22] As most high school and college athletes do not understand the potential repercussions of mTBI, many fail to report occurrences of brain injury to coaches or athletic trainers, electing to play through the injury, putting themselves at greater risk for injury.[23]

One common perception reported by athletes who use protective headgear is a feeling of increased protection, which in turn causes them to act more recklessly on the

field of play.[24] Players who have no previous history of TBI were more likely to report the increase in feeling of safety as their primary reason for wearing the equipment, whereas players with a history of TBI wear the devices to prevent injury recurrence. The two most common reasons athletes do not like wearing protective headgear are discomfort (61%) and heat (57%). These factors must be considered when designing and creating protective headgear for athletes. Athletes in this study reported a statistically significant feeling of increased protection when wearing the Q-Collar on the field, which must be investigated in the future to understand whether or not players are putting themselves at a greater risk of mTBI due to this extra confidence.

The designer of protective equipment for any sporting activity must consider such factors as the fit, weight, restriction of motion, limitation of visual or auditory sensory input, usefulness, comfort, durability, user acceptability of the product, and the economic position of the buyer.[25] Usability and tolerability are two of the most important aspects to athletes, because regardless of how effective the protective equipment is, if it isn't comfortable or doesn't look good it more than likely will not be worn consistently. Both usability and tolerability were addressed in the study as overall compliance, where overall compliance was 88.7% and 77% responded that they would wear the collar again. The designer must also carefully consider "trade-offs," as every item of protective equipment has certain advantages and disadvantages. By designing to eliminate one risk or danger the manufacturer may create another. A design that selects or uses a material for one specific purpose may unintentionally create a problem if the material is to be used or combined with another material.[25]

Human factor research is vital to the success and utilization of any protective sports device. However, such research can come with a variety of issues such as ethical integrity and compliance. Therefore, all research data compiled from human factors can certainly be beneficial when conducted properly. A study was done recently on the risks to snow sport safety and wearing helmets as a human factors approach.[26] The study had 100+ students tracking telemetry changes in their helmets as well as GPS devices during their snow sport activity. The authors found that the athlete's snow helmets were not sufficient in protecting the head and brain at the rating they were tested at previously. The "over 40G hits," were mainly sustained by male snowboarders, the ones moving faster and with more recklessness than the other snow sport athletes. Those over 40G hits could potentially be more likely to cause a concussive event. The helmet, the protective equipment that has been the gold standard for decades to prevent head injury, wasn't sufficiently protective enough, especially to the higher levels of contact that were sustained by the harder and faster collisions to the head and brain. Research continually shows that there is no helmet in existence that can prevent every head injury from occurring, no matter how significant the rating system or accrediting body may be.

Limitations

The primary limitations to this study were the small sample size of 31 players from only one team, and all response data were self-reported data. In addition, this study only took place over one season. The margin of error for this data is +/- 18%. No measures of brain trauma and/or injuries were made. For the free response question, responses were generalized into categories, so not all individual's concerns and suggestions were reported.

CONCLUSION

Given the above limitations, the results of this study suggest that a collar-like device designed to reduce mTBI via mild jugular compression was well received, utilized, and tolerated by high school football players. The athletes reported little to no perceived performance hindrance due to the usage of the collar. The use and experience of the collar was generally positive, as players felt an increased sense of protection on the field and most would continue to wear the collar if available. The players often forgot that the collar was on when playing and rarely removed it when they were not playing or in between plays. More research must be done in larger and more diversified populations to increase the accuracy of results. In addition, the above use results need to be evaluated with regard to head trauma/concussion, i.e. the effectiveness of the Q-Collar.

References

1. Sports Concussion Statistics. 2013; http://www.headcasecompany.com/concussion_info/stats_on_concussions_sports.
2. Kulkarni S, Gao X-L, Horner S, Zheng J, David N. Ballistic helmets–their design, materials, and performance against traumatic brain injury. *Composite Structures.* 2013;101:313-331.
3. Zezima K. How Teddy Roosevelt helped save football. 2014; May 29, 2014:https://www.washingtonpost.com/news/the-fix/wp/2014/05/29/teddy-roosevelt-helped-save-football-with-a-white-house-meeting-in-1905/.
4. Hoshizaki TB, Brien SE. The science and design of head protection in sport. *Neurosurgery.* 2004;55(4):956-966; discussion 966-957.
5. Schneider DK, Grandhi RK, Bansal P, et al. Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies. *Br J Sports Med.* 2016.
6. Navarro RR. Protective equipment and the prevention of concussion - what is the evidence? *Current sports medicine reports.* 2011;10(1):27-31.
7. Daneshvar DH, Baugh CM, Nowinski CJ, McKee AC, Stern RA, Cantu RC. Helmets and mouth guards: the role of personal equipment in preventing sport-related concussions. *Clin Sports Med.* 2011;30(1):145-163, x.
8. Viano DC, Withnall C, Halstead D. Impact performance of modern football helmets. *Annals of biomedical engineering.* 2012;40(1):160-174.
9. McGuine TA, Hetzel S, McCrea M, Brooks MA. Protective equipment and player characteristics associated with the incidence of sport-related concussion in high school football players: a multifactorial prospective study. *The American journal of sports medicine.* 2014;42(10):2470-2478.
10. Collins M, Lovell MR, Iverson GL, Ide T, Maroon J. Examining concussion rates and return to play in high school football players wearing newer helmet technology: a three-year prospective cohort study. *Neurosurgery.* 2006;58(2):275-286; discussion 275-286.
11. Gourley MM, McLeod TCV, Bay RC. Awareness and recognition of concussion by youth athletes and their parents. *Athletic Training and Sports Health Care.* 2010;2(5):208-218.
12. Benson BW, McIntosh AS, Maddocks D, Herring SA, Raftery M, Dvorak J. What are the most effective risk-reduction strategies in sport concussion? *Br J Sports Med.* 2013;47(5):321-326.
13. Meaney DF, Smith DH. Biomechanics of concussion. *Clin Sports Med.* 2011;30(1):19-31, vii.
14. Stemper BD, Pintar FA. Biomechanics of concussion. *Prog Neurol Surg.* 2014;28:14-27.
15. Barbic D, Pater J, Brison RJ. Comparison of mouth guard designs and concussion prevention in contact sports: a multicenter randomized controlled trial. *Clinical*

journal of sport medicine : official journal of the Canadian Academy of Sport Medicine. 2005;15(5):294-298.
16. Farrey T. Preps at Greater Concussion Risk. 2013; http://www.espn.com/espn/story/_/id/9902116/report-details-concussion-risks-high-school-athletes, 2016.
17. Halstead ME, Walter KD, Council on Sports M, Fitness. American Academy of Pediatrics. Clinical report--sport-related concussion in children and adolescents. *Pediatrics.* 2010;126(3):597-615.
18. Myer GD, Smith D, Barber Foss KD, et al. Rates of concussion are lower in National Football League games played at higher altitudes. *The Journal of orthopaedic and sports physical therapy.* 2014;44(3):164-172.
19. Smith DW, Myer GD, Currie DW, Comstock RD, Clark JF, Bailes JE. Altitude Modulates Concussion Incidence: Implications for Optimizing Brain Compliance to Prevent Brain Injury in Athletes. *Orthop J Sports Med.* 2013;1(6):2325967113511588.
20. Smith DW, Bailes JE, Fisher JA, Robles J, Turner RC, Mills JD. Internal jugular vein compression mitigates traumatic axonal injury in a rat model by reducing the intracranial slosh effect. *Neurosurgery.* 2012;70(3):740-746.
21. Valovich McLeod TC, Schwartz C, Bay RC. Sport-related concussion misunderstandings among youth coaches. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine.* 2007;17(2):140-142.
22. Lee HR, Resch JE, Han TK, Miles JD, Ferrara MS. Sport-Related Concussion Knowledge and Occurrence: A Survey of High School and College Athletes in South Korea. *International Journal of Athletic Therapy & Training.* 2016;21(2).
23. Register-Mihalik JK, Guskiewicz KM, McLeod TCV, Linnan LA, Mueller FO, Marshall SW. Knowledge, attitude, and concussion-reporting behaviors among high school athletes: a preliminary study. *Journal of athletic training.* 2013;48(5):645-653.
24. Finch CF, McIntosh AS, McCrory P. What do under 15 year old schoolboy rugby union players think about protective headgear? *Br J Sports Med.* 2001;35(2):89-94.
25. Hoerner EF. Ice Hockey Protective Equipment—Its Value, Capabilities, and Limitations. *Safety in Ice Hockey*: ASTM International; 1989.
26. Dickson TJ, Trathen S, Waddington G, Terwiel FA, Baltis D. A human factors approach to snowsport safety: Novel research on pediatric participants' behaviors and head injury risk. *Appl Ergon.* 2016;53 Pt A:79-86.

Table Legends

Figure Legends

Table 1: Collar effect on performance response statistics

	Mean	Standard Deviation	Median	95% CI	Lower Quartile	Upper Quartile	Significant Response	n
Tackling	0.37	1.19	0	(-0.09, 0.82)	0	0	NEUTRAL	30
Running	0.3	1.09	0	(-0.11, 0.71)	0	0	NEUTRAL	30
Max Effort	0.61	1.48	0	(0.06, 1.17)	0	0	IMPROVED	31
Passing	-0.07	0.27	0	(-0.18, 0.03)	0	0	NEUTRAL	27
Receiving	0.24	0.87	0	(-0.10, 0.58)	0	0	NEUTRAL	29
Blocking	0.71	1.49	0	(0.15, 1.27)	0	0	IMPROVED	31
Change in Technique	-1.71	2.66	0	(-2.71, -0.71)	-5	0	INFREQUENT	31

Each question scored -5 to 5, where -5 is infrequent, 0 is neutral, and +5 is frequent

Table 2: Collar effect on performance summary table

	INFREQUENT	NEUTRAL	FREQUENT	n
	-5 to -2	-1 to +1	+2 to +5	
Tackling	0.0%	90.0%	10.0%	30
Running	0.0%	86.7%	13.3%	30
Max Effort	0.0%	80.6%	19.4%	31
Passing	0.0%	100.0%	0.0%	27
Receiving	0.0%	89.7%	10.3%	29
Blocking	0.0%	80.6%	19.4%	31
Change in Technique	41.9%	51.6%	6.5%	31

Table 3: Collar use and experience response statistics

	Mean	Standard Deviation	Median	95% CI	Lower Quartile	Upper Quartile	Significant Response	n
Comfort	0.16	2.37	-1	(-.0.72, 1.05)	-1.5	2.5	NEUTRAL	31
Swallowing*	1.17	2.78	0	(0.11, 2.23)	-1	4.75	NO EFFECT	31
Breathing	1	3.04	0	(-0.16, 2.16)	-1	4	NEUTRAL	31
Talking*	2.63	2.43	3.5	(1.71, 3.56)	0	5	NO EFFECT	31
Mental Clarity*	2.74	2.39	4	(1.85, 3.64)	0	5	NO EFFECT	31
Hearing	0.52	1.43	0	(-0.02, 1.05)	0	0	NEUTRAL	31
Protection*	2.06	1.82	3	(1.38, 2.75)	0	3	INCREASE	31
Collar Movement	-0.03	2.68	-0.5	(-1.06, 0.99)	-2	2	NEUTRAL	31
Overall Experience*	2.97	1.91	3	(2.25, 3.68)	2	5	POSITIVE	31
Continue Wearing?*	3	2.53	3	(2.05, 3.95)	2	5	POSITIVE	31

Each question scored -5 to 5, where -5 is infrequent, 0 is neutral, and +5 is frequent

Table 4: Collar use and experience summary table

	INFREQUENT	NEUTRAL	FREQUENT	n
	-5 to -2	-1 to 1	2 to 5	
Comfort	29.0%	35.5%	35.5%	31
Swallowing	16.1%	48.4%	35.5%	31
Breathing	22.6%	38.7%	38.7%	31
Talking	0.0%	45.2%	54.8%	31
Mental Clarity	0.0%	38.7%	61.3%	31
Hearing	0.0%	87.1%	12.9%	31
Protection	0.0%	45.2%	54.8%	31
Collar Movement	41.9%	19.4%	38.7%	31
Overall Experience	0.0%	22.6%	77.4%	31
Continue Wearing?	6.5%	16.1%	77.4%	31

Table 5: Collar Use and Storage response statistics

	Mean	Standard Deviation	Median	95% CI	Lower Quartile	Upper Quartile	Significant Response	n
Remove When Not Playing?	-0.39	3.92	0	(-1.85, 1.08)	-4.5	3	NEUTRAL	31
Remove Between Quarters?*	-2.48	3.24	-5	(-3.70, -1.27)	-5	0	INFREQUENT	31
Forget it was on?*	2.77	2.1	3	(1.97, 3.56)	2	4	FREQUENT	31
How Often Wash/Clean?*	-2.03	2.96	-3	(-3.14, -0.92)	-5	1	INFREQUENT	31

Each question scored -5 to 5, where -5 is infrequent, 0 is neutral, and +5 is frequent

Table 6: Collar use and storage summary table

	INFREQUENT	NEUTRAL	FREQUENT	n
	-5 to -2	-1 to 1	2 to 5	
Remove When Not Playing?	45.2%	9.7%	45.2%	31
Remove Between Quarters?	64.5%	16.1%	19.4%	31
Forget it was on?	6.5%	12.9%	80.6%	31
How Often Wash/Clean?	61.3%	16.1%	22.6%	31

Figure 1

Click here to download Figure Figure 1.jpg

Figure 2

Click here to download Figure Figure 2.jpg

Subject Number:_____
Collar Size: _____

Date:_____
Height: _____**in**
Weight:_____**lbs**

COLLAR EFFECT ON PERFORMANCE.
Score the device the in the following categories (as compared to not wearing a collar).

	DECREASED PERFORMANCE					NEUTRAL				IMPROVED PERFORMANCE		
TACKLING	-5	-4	-3	-2	-1	0	1	2	3	4	5	
	DECREASED PERFORMANCE					NEUTRAL				IMPROVED PERFORMANCE		
RUNNING	-5	-4	-3	-2	-1	0	1	2	3	4	5	
ABILITY TO PERFORM AT MAX EFFORT	DECREASED PERFORMANCE					NEUTRAL				IMPROVED PERFORMANCE		
	-5	-4	-3	-2	-1	0	1	2	3	4	5	
	DECREASED PERFORMANCE					NEUTRAL				IMPROVED PERFORMANCE		
PASSING	-5	-4	-3	-2	-1	0	1	2	3	4	5	N/A
	DECREASED PERFORMANCE					NEUTRAL				IMPROVED PERFORMANCE		
RECEIVING	-5	-4	-3	-2	-1	0	1	2	3	4	5	N/A
	DECREASED PERFORMANCE					NEUTRAL				IMPROVED PERFORMANCE		
BLOCKING	-5	-4	-3	-2	-1	0	1	2	3	4	5	N/A
DID YOU FEEL THAT BY WEARING THE COLLAR, YOU CHANGED YOUR TECHNIQUES ON THE FIELD?	NO					NEUTRAL					YES	
	-5	-4	-3	-2	-1	0	1	2	3	4	5	N/A

COLLAR USE AND EXPERIENCE.
Score the device the in the following categories.

	NOT COMFORTABLE					NEUTRAL				VERY COMFORTABLE		
COMFORT	-5	-4	-3	-2	-1	0	1	2	3	4	5	
	DIFFICULT					NEUTRAL				EASY		
SWALLOWING	-5	-4	-3	-2	-1	0	1	2	3	4	5	
	RESTRICTED					NEUTRAL				EASY		
BREATHING	-5	-4	-3	-2	-1	0	1	2	3	4	5	
	DIFFICULT					NEUTRAL				EASY		
TALKING	-5	-4	-3	-2	-1	0	1	2	3	4	5	
	UNCLEAR					NEUTRAL				CLEAR		
MENTAL CLARITY	-5	-4	-3	-2	-1	0	1	2	3	4	5	

Version 1.0

Figure 2B

Click here to download Figure Figure 2B.jpg

HEARING	DECREASED					NEUTRAL					IMPROVED
	-5	-4	-3	-2	-1	0	1	2	3	4	5
PROTECTION	DECREASED FEELING OF PROTECTION					NEUTRAL					INCREASED FEELING OF PROTECTION
	-5	-4	-3	-2	-1	0	1	2	3	4	5
COLLAR MOVEMENT	FREQUENT MOVEMENT					NEUTRAL					NO MOVEMENT
	-5	-4	-3	-2	-1	0	1	2	3	4	5
OVERALL EXPERIENCE	NEGATIVE					NEUTRAL					POSITIVE
	-5	-4	-3	-2	-1	0	1	2	3	4	5
WOULD YOU CONTINUE TO WEAR THE COLLAR?	NO					NEUTRAL					YES
	-5	-4	-3	-2	-1	0	1	2	3	4	5

COLLAR CARE & STORAGE.
Score the device the in the following categories.

DID YOU REMOVE THE COLLAR WHEN NOT ON THE FIELD?	INFREQUENTLY					NEUTRAL					FREQUENTLY
	-5	-4	-3	-2	-1	0	1	2	3	4	5
DID YOU REMOVE THE COLLAR BETWEEN QUARTERS?	INFREQUENTLY					NEUTRAL					FREQUENTLY
	-5	-4	-3	-2	-1	0	1	2	3	4	5
DID YOU EVER FORGET THE COLLAR WAS ON?	INFREQUENTLY					NEUTRAL					FREQUENTLY
	-5	-4	-3	-2	-1	0	1	2	3	4	5
HOW OFTEN DID YOU WASH OR CLEAN THE COLLAR?	INFREQUENTLY					NEUTRAL					FREQUENTLY
	-5	-4	-3	-2	-1	0	1	2	3	4	5

HOW DID YOU STORE THE COLLAR?

- ☐ In provided box
- ☐ In your equipment bag
- ☐ In locker
- ☐ Other

HOW WOULD YOU IMPROVE THE COLLAR?

Version 1.0