Journal of Science and Medicine in Sport 22 (2019) 1102–1107

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

# A helmetless-tackling intervention in American football for decreasing head impact exposure: A randomized controlled trial

Erik E. Swartz[a,f,*], Jay L. Myers[a,f], Summer B. Cook[f], Kevin M. Guskiewicz[b], Michael S. Ferrara[f], Robert C. Cantu[c], Hong Chang[d], Steven P. Broglio[e]

[a] University of Massachusetts — Lowell, Department of Physical Therapy and Kinesiology, United States
[b] University of North Carolina — Chapel Hill, United States
[c] Emerson Hospital, Department of Neurosurgery, United States
[d] Clinical and Translational Sciences Institute, Tufts University, United States
[e] University of Michigan, School of Kinesiology, United States
[f] University of New Hampshire, Department of Kinesiology, United States

ARTICLE INFO

*Article history:*
Received 1 November 2018
Received in revised form 1 April 2019
Accepted 30 May 2019
Available online 7 June 2019

*Keywords:*
Athletic injuries
Adolescent
Risk reduction behavior
Concussion
Tackling

ABSTRACT

*Objectives:* To evaluate a behavioral intervention to reduce head impact exposure in youth playing American football.
*Design:* Nested randomized controlled trial.
*Methods:* Participants, ages 14–17 years, wore head impact sensors (SIM-G™) during two seasons of play. Those randomized to the intervention group underwent weekly tackling/blocking drills performed without helmets (WoH) and shoulder pads while the control group trained as normal, matching frequency and duration. Research personnel provided daily oversight to maintain fidelity. Head impact frequency (≥10 g) per athlete exposure (ImpAE) was analyzed over time (two 11-week seasons) using mixed effect models or ANCOVA. Secondary outcomes included exposure-type (training, game) and participation level (entry-level versus upper-level secondary education).
*Results:* One-hundred fifteen participants (59 WoH, 56 control) met compliance criteria, contributing 47,382 head impacts and 10,751 athlete exposures for analysis. WoH had fewer ImpAE during games compared to control participants at weeks 4 ($p = 0.0001$ season 1, $p = 0.0005$ season 2) and 7 ($p = 0.0001$ both seasons). Upper-level WoH participants had less ImpAE during games than their matched controls at weeks 4 ($p = 0.017$ and $p = 0.026$) and 7 ($p = 0.037$ and $p = 0.014$) in both seasons, respectively. Upper-level WoH also had fewer ImpAE during training at week 7 ($p = 0.015$) in season one.
*Conclusions:* Tackling and blocking drills performed without a helmet during training reduced the frequency of head impacts during play, especially during games. However, these differences disappeared by the end of the season. Future research should explore the frequency of behavioral intervention and a dose-response relationship considering years of player experience.
*Trial registration:* ClinicalTrials.gov # NCT02519478.


### Practical implications

- American football players may benefit from helmetless tackling and blocking training.
- Sustained behavior changes require consideration of the dose-response relationship.
- Protective headgear may introduce unintended behaviors.

## 1. Introduction

Use of the head as the point-of-contact in American football is persistent, well documented,[1,2] and a direct cause of catastrophic injury.[3] Head impacts are directly related to risk of concussion[4] and cervical spine injury[5] and repeated head impact exposure creates physiologic changes in the brain that are thought to result in long term neurocognitive pathologies.[6–8] Head-initiated behavior in American football may persist due to the false sense of security inherent to wearing a helmet. Risk homeostasis theory contends

*Abbreviations:* WoH, without helmets; AE, athlete exposure; ImpAE, impacts per athlete exposure.

* Corresponding author.
*E-mail address:* erik.swartz@uml.edu (E.E. Swartz).

https://doi.org/10.1016/j.jsams.2019.05.018
1440-2440/

that an individual's choice of behavior is influenced by their perception for risk of injury.[9] An example occurred when hard-shell helmets were introduced into American football in the 1950s and a "spear-tackling" behavior emerged, leading to a spike in catastrophic head and neck injuries into the early 1970s.[10]

Despite the helmet's inability to prevent concussions or eliminate forces transmitted to the brain, the helmet is the most important piece of protective equipment in American football. Continued design and material innovations enhance its impact absorption capability,[11] yet such advancements arguably lower the wearer's perception of risk even further. By comparison, the sport of rugby involves high energy collisions and tackling which puts the head at risk for injury. Recent research utilizing impact sensors in amateur and youth rugby report comparable head impact frequencies as those reported in similar age groups from American football.[12] However, rugby players do not display behaviors of initiating contact with the head, at least in part, because it remains unprotected. In fact, when modified headgear was used in a randomized controlled trial of rugby union players, the additional head padding was associated with an increase in injury risk.[13] Likewise in football, head impacts during non-tackling, "helmets-only" practices were reported as being greater compared to games in secondary school level players.[14]

There has been a rejuvenated focus on tackling skills-training in American football in response to growing concerns over head safety, often modelling the sport of rugby. The National Football League (New York, NY) has promoted a rugby-style, shoulder-lead tackling technique publicly available through the internet, and anecdotally in wide-spread use.[15] Similarly, the Heads-up Football program instituted nationally by USA Football, Inc. (Indianapolis, IN) for many years has recently incorporated rugby-style tackling drills. These measures are endorsed as head-protective and improving safety during tackling in American football despite little to no empirical evidence to support their effectiveness.[16]

Consequently, practicing helmetless tackling and blocking techniques by American football players, akin to rugby, is theorized to better emphasize proper head placement and counter the risk homeostasis phenomenon associated with wearing a helmet. Indeed, a small prospective study of a helmetless-tackling intervention with collegiate level American football players reduced head impact frequency by 28% in one season.[17]

Given the dearth of high-level evidence to support the effectiveness for reducing head impact exposure in American football, our purpose was to test the hypothesis that secondary school aged American football players who regularly and progressively practice tackling and blocking skills without a helmet will experience fewer head impacts compared to controls. Secondarily, we sought to explore this effect in different exposure types (games versus training) and level of experience (entry-level versus upper-level secondary education).

## 2. Methods

A randomized, controlled trial (clinicaltrials.gov #NCT02519478) was conducted over two football seasons with players having at least two years of eligibility on secondary school football teams (i.e., 9–11th years of secondary education). Funding sponsors had no role in the study design, analysis and interpretation, and right to approve or disapprove publication of the finished manuscript. Methods were approved by the university's institutional review board. Following agreement by school administrators, volunteers were recruited in group settings among entry-level and upper-level teams at four regional high schools prior to the first season. Written participant assent and parent or guardian consent were acquired. Participants were assigned by computer-generated randomizer on a 1:1 ratio to a without-helmet (WoH) intervention or control group. Player position was not a factor for randomization as athletes at this level often play both offense and defensive positions. Groups were nested within teams and maintained for both seasons. All participants received and wore a new Riddell Revolution Speed™ helmet (Riddell, Elyria, OH) for the duration of the study. Helmets underwent reconditioning between seasons and were properly fitted by the teams' trained designee.

The helmetless tackling and blocking intervention (HuTT®; University of New Hampshire, Durham, NH) used in this study consisted of a 3-phase progression (i.e., Static, Dynamic, Functional) of 10 instructional drills performed without helmets and shoulder pads. The HuTT® program's helmetless approach is intended to develop and reinforce motor behaviors that explicitly remove the head as a point-of-contact.[17] Intervention sessions were approximately 10 min in duration and consisted of a prescribed set of two drills. Participants executed techniques against tackling bags or a padded shield held by teammates, alternating contact from the right and left directions. The intervention group completed the drill protocol at a frequency of four sessions per week during the pre-season and two sessions per week during the competition season. Sessions were held at the beginning or end of training and supervised by trained coaches and research personnel. The control group participated in football-related training, as normal, during intervention sessions of matching duration under separate coaching supervision on another part of the training facility.

The intervention was led by designated coaches for each team. Coaches were selected based on respective roles among the coaching staff and their responsibility with the cohort of participants (i.e., entry-level versus upper-level teams). At the outset, coaches received education on the protocol by attending a one-day workshop covering research objectives and intervention principles, in addition to on-field demonstrations of the 10-drill progression. A detailed handbook and corresponding video media (DVD) of the protocol were used as reference material. Before season two, the intervention workshop and on-field demonstrations were repeated, and coaches were given access to a mobile-based web application with protocol videos (Retrieve Technologies, Manchester, NH). The mobile app replaced the DVD to enhance on-field accessibility via smart phone. To ensure intervention compliance and content competency, coaches were instructed to review the handbook and DVD or mobile app with on-site research personnel immediately prior to an intervention session and at least twice for each drill. On-going observational evaluations and critical feedback were performed by the same research personnel, while principle investigators and a coaching consultant visited team sites on a rotating basis.

Individually worn Smart Impact Monitors (SIM-G™, Triax Technologies, Inc., Norwalk, CT) were used to record head impact biomechanics of intervention and control group participants during each training and game. The SIM-G consists of a low-g and high-g tri-axial accelerometer to measure head impact acceleration (g's), in addition to a tri-axial gyroscope to record directional coordinates (azimuth, elevation) of the impact's location relative to the head's estimated center of mass. Impacts resulting in peak linear accelerations greater than 10 g were transmitted from the SIM-G to a sideline receiver (Sky-I™) via radio frequency (900 MHz) and stored on a proprietary cloud-based server. As per the manufacturer's instructions, the SIM-G was worn in a fitted head band or skull-cap under the helmet, centering the sensor on the back of the head along the nuchal line. Validity and reliability for the SIM-G to accurately record head impacts has been reported elsewhere.[18,19] Data capture was monitored in real-time by on-site research personnel. Raw data were exported weekly from cloud storage.

Participant compliance was monitored daily by on-site research personnel and athlete exposures (AE), defined as entry into any training or game regardless of duration, were recorded. Compliance for both intervention and control groups was defined as an average attendance rate ≥60% for all potential AE's over the two seasons. Participants were required to obtain an attendance rate of ≥60% in each season of the intervention.

Prior to statistical analysis, raw data were first filtered by proprietary algorithm for removal of accelerations not associated with a true head impact (i.e., false impacts defined as NITs, Triax Technologies, Inc.), then cross referenced to AE attendance records. Data were then filtered by timestamp (h:min:s) for AE start and stop times, intervention sessions when helmets were not worn, and data having two or more identical timestamps likely associated with running and jumping.[20] Remaining impacts associated with each exposure were examined for outliers (i.e., spurious accelerations[21]) within team cohorts by calculating the upper bound (1.5 × IQR) for each AE and, when exceeded, replacing it with the participant's mean impact frequency[22] per AE (16 AE's from 14 participants were addressed using this approach).

A power analysis using G*Power (version 3.1.3, Universitat Kiel, Germany) was conducted to analyze data on the weekly average basis with one (1) week of pre-intervention baseline measurement and 10 follow-up measurements (10 weeks). Assuming a significance level of 0.05, 80% of power, and correlation of 0.7 among the baseline and follow-up measurements, a sample size of 50 players per arm was estimated to detect an effect size of 0.48 at any post follow-up time point for a continuously measured outcome variable using mixed effect modeling.

Statistical analysis of data was performed using STATA® version 13 (StataCorp LP, College Station, TX). Independent variables were defined as group (WoH, control), time (weeks 1–11 and seasons 1–2) and playing level at the time of enrollment (entry-level, 9th year versus upper-level, 10–11th year). Frequency of impacts per athlete exposure (ImpAE) was used to test differences among groups and playing levels across time using multilevel effect mixed models ($p < 0.05$). The quadratic form for time was used to represent the non-linear nature of the trajectory over time in these models. The predicted values at mean level of all covariates at each time point were obtained and compared between WoH and control groups using contrast formations. In the mixed effect models, these tests were performed through chi-square test using the log likelihood difference between full model (non-constraints due to the difference of control and intervention) and reduced model (constraints due to the equality of control and intervention). In the event the mixed model could not attain convergence, analysis of covariance (ANCOVA) with repeated measure was used.

## 3. Results

A total of 180 male participants (14–17 years of age) were initially enrolled and nested within teams to WoH (n = 89; height = 175.7 ± 8.0 cm, mass = 76.1 ± 18.3 kg) and control (n = 91; 175.7 ± 8.7 cm, 74.8 ± 18.5 kg) groups. Distribution of player level was greatest among the 9th year of education (n = 69), followed by the 10th year (n = 66) and the 11th year (n = 45), respectively. One hundred-fifteen participants (n = 115; 59 WoH, 56 control) successfully matriculated and met research compliance criteria after two seasons (Fig. 1, CONSORT flow diagram). The greatest attrition occurred between seasons from participants leaving the team.

A total of 47,382 head impacts were used in the final analysis. WoH participants recorded 21,945 total head impacts (12,549 in season 1 and 9396 in season 2) along with 5458 total athlete exposures (2738 and 2720, respectively). Control participants recorded 25,437 total impacts (14,583 and 10,854) and 5293 total athlete exposures (2646 and 2647, respectively).

Predicted group means (±SE) with effect sizes for head impact frequency per athlete exposure at weeks 1, 4, 7, and 11 each season are found in Table 1. WoH participants had fewer ImpAE during games compared to control at weeks 4 ($p = 0.0001$ season 1, $p = 0.0005$ season 2) and 7 ($p = 0.0001$ both seasons). The upper-level WoH participants had less ImpAE during games than controls at weeks 4 ($p = 0.017$ and $p = 0.026$) and 7 ($p = 0.037$ and $p = 0.014$) in both seasons, respectively. Upper-level WoH participants also had fewer ImpAE at week 7 during training ($p = 0.015$) versus control in season 1.

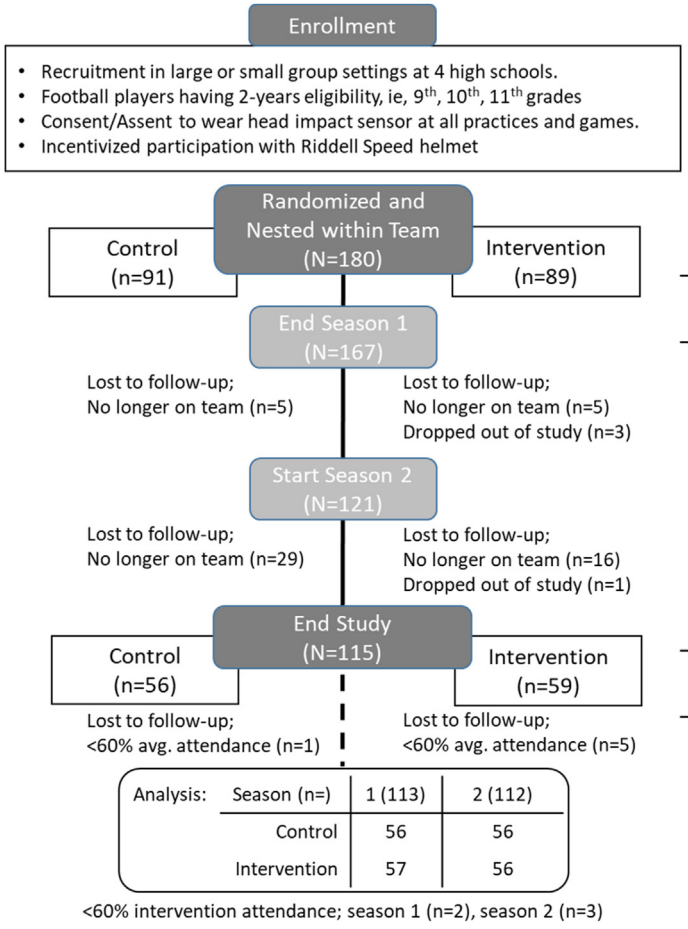
## 4. Discussion

To our knowledge, this is the first randomized controlled trial to study a behavioral program for reducing head impact exposure in adolescents participating in American football. Our most important finding was that players participating in the helmetless tackling and blocking intervention experienced 26–33% fewer game related ImpAE at two identical time points across both seasons compared to the control. Intervention participants initially enrolled in their 10th and 11th year of education (upper-level) during for the first season had decreased head impact frequency per AE during beginning and mid-season games by 28–33% in two consecutive years, and fewer training-specific impacts at a single time point in season 1. Taken together, these results support a benefit for reducing head impact exposure following a systematic progression of tackling and blocking training without a helmet.

Reports of effectiveness from strategies employed for head impact reduction in football players 14–18 years of age is limited. For example, one study compared head impacts sustained across two seasons during which a rule change for limiting full contact in training was implemented. Authors reported that players sustained 15,398 head impacts (average of 592/player) in a season before the rule went into effect, and 8269 head impacts (average of 345/player) after.[23] This comparison was not randomized, however, and only a small subset of participants were consistent across the two seasons. Similarly, non-randomized research on USA Football's Heads-Up training program, combined with training-contact restrictions, reported less impacts during training but not during games.[16] Frequency of impacts[24] and risk for concussion[25] are highest during games for high school football, thus it was encouraging to detect a reduction in head impacts during games in our study. In fact, large effect sizes were closely associated with game exposure-types in both years when all participants were analyzed, and this pattern held when analyzing upper-level players. Of note, no rules or policies for contact restrictions for football were put into place during the two years this investigation was conducted.

It is interesting to note the limited effect of the intervention during training exposures. This may be the result of a significant proportion of training not involving full-contact play, whether by rule or coaching preference, and thus mitigating the number of impacts and opportunity for the intervention to be employed. Team play during training was often 'scripted' and did not involve live tackling to allow players an opportunity for rehearsing game strategy without the associated frequency of head impacts. It is also possible that intervention participants, having gleaned benefit from the training, may indirectly benefit their control-group teammates by having avoided head-first contact against them. This is plausible given overall impacts per exposure for both groups decreased during training towards the end of the season.

Learning a new skill is dependent on repetition[26,27] and the necessary number of repetitions for a helmetless tackling intervention to have an effect is not fully understood. Prior research has reported




| Start – Season 1 | Grade Level 9th | 10th | 11th | Total |
|---|---|---|---|---|
| Control | 34 | 34 | 23 | 91 |
| Intervention | 35 | 32 | 22 | 89 |
| Total | 69 | 66 | 45 | 180 |

| End – Season 2 | Grade Level 10th | 11th | 12th | Total |
|---|---|---|---|---|
| Control | 22 | 21 | 13 | 56 |
| Intervention | 20 | 24 | 15 | 59 |
| Total | 42 | 45 | 28 | 115 |

**Fig. 1.** CONSORT flow diagram: research participants were enrolled at the outset from two entry-level and three upper-level, secondary school teams. Starting the second season, the entry-level participants advanced to the upper-level. Participant matriculation was monitored at two time points between the initial enrollment and end of study. By the end of season one, 13 participants were lost to follow-up, and beginning year two, 46 were lost to follow-up. The study ended with a total of 115 participants meeting all research criteria. The final analysis excluded participants who did not have a 60% attendance rate for the intervention.

collegiate-aged athletes to respond positively with a once-weekly dose.[17] Data from this study show that upper-level participants responded to the intervention with a twice-weekly intervention, or a dose-ratio of two interventions per five exposures per week. The temporary nature of positive changes throughout the season and the uncertain effect in our entry-level participants raises a question about the relationship between training dosage and a participant's age and experience level. Entry-level football players (9th year) are generally transitioning between secondary and senior secondary school sports and often find themselves on developmental teams with coaches having less experience.[28] Also, their degree of physical and cognitive maturation is more variable, translating into different stages of motor coordination and agility development. Therefore, it is possible that less-experienced, adolescent and youth players require a higher frequency of technique training delivered from more-experienced coaches to adopt the appropriate skills. Never the less, two interventions/week in our study resulted in approximately 1–3 fewer impacts per practice and game, respectively. Over the course of an 11-week season, this can be estimated to result in a range of 55–73 fewer head impacts sustained.

The authors recognize several limitations of the study. Despite advances in head impact sensor technology and laboratory methods for measuring sports related head accelerations, there is a lack of *in vivo* evidence associated with the reliability and validity of low-cost, wearable instruments. Laboratory studies have shown the SIM-G to lack equivalence to a reference[29] for peak linear and rotational acceleration and velocity, yet it was found to be more accurate at recording peak translational acceleration than helmet-based sensors.[30] More important to this study, the SIM-G had the highest detection rate of head impacts (95.8%, 207/216) compared across common devices in one study[31] with an overall detection rate of 80% (24/30) in another,[18] despite missed detections of to the front boss and side center positions. Secondly, while there is grounding in risk-homeostasis theory[9] for the observed outcome, the perception of risk in participants who underwent the intervention of practicing without helmets was not measured. Prior research has associated a low level of perceived risk with an increase in risk injury[32], and the helmeted athlete's perceived risk is influenced by the sense of security from wearing a helmet.[33] Third, our compliance criteria for participants to be present for at least 60% of training and games may not be representative of the population. Some children participating in football may not be present every day an intervention is held, and thus, may not receive a benefit. Finally, the clinical threshold for avoiding neurodegenerative deficits from a reduction in head impact exposure is not well understood. However, a growing body of research is elucidating the physiological response in the brain due to head impact exposure (frequency and force) and location.[7,8] For example, Slobounov et al.[7] reported increases in default-mode network connectivity over the course of the season as associated with athletes who experienced a broader distribution of training related impacts $\geq$80 g. Thus, not only is reducing frequency of impacts important, but also the magnitude of such impacts over the course of a season.

**Table 1**
Head impact frequency per athlete exposure (±SE) for all exposure-types, training only, and games only.

| | Season | Week | All exposure-types | | | Training only | | | Game only | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Control | WoH | ES | Control | WoH | ES | Control | WoH | ES |
| All participants | 1 | **1** | 5.3 (0.97) | 4.7 (0.97) | 0.43 | 5.0 (0.90) | 4.9 (0.90) | 0.08 | 7.5 (0.95) | 5.2 (0.92) | *1.79* |
| | | **4** | 5.7 (0.96) | 4.9 (0.96) | 0.58 | 4.5 (0.87) | 4.4 (0.87) | 0.08 | **8.8 (0.48)** | **5.9 (0.48)**[a] | *4.18* |
| | | **7** | 5.9 (1.01) | 5.0 (1.01) | 0.63 | 4.2 (0.90) | 3.9 (0.90) | 0.24 | **9.5 (0.51)** | **6.5 (0.51)**[a] | *4.20* |
| | | **11** | 5.8 (1.14) | 4.7 (1.13) | 0.7 | 4.1 (1.02) | 3.5 (1.01) | 0.42 | 9.4 (0.90) | 7.1 (0.86) | *1.85* |
| | 2 | **1** | 3.4 (1.22) | 2.7 (1.22) | 0.41 | 3.0 (1.13) | 2.4 (1.13) | 0.38 | 4.8 (0.88) | 3.7 (0.86) | *0.88* |
| | | **4** | 4.0 (1.21) | 3.4 (1.21) | 0.35 | 2.5 (1.10) | 2.4 (1.10) | 0.06 | **8.9 (0.48)** | **6.6 (0.48)**[a] | *3.32* |
| | | **7** | 4.5 (1.25) | 3.7 (1.25) | 0.44 | 2.5 (1.13) | 2.3 (1.13) | 0.13 | **10.0 (0.52)** | **7.3 (0.51)**[a] | *3.78* |
| | | **11** | 5.0 (1.36) | 3.5 (1.35) | 0.77 | 3.4 (1.22) | 2.3 (1.22) | 0.64 | 6.6 (0.91) | 4.7 (0.87) | *1.52* |
| Upper-level only | 1 | **1** | 4.9 (0.68) | 4.5 (0.65) | 0.42 | 4.6 (0.62) | 4.7 (0.58) | 0.12 | 7.2 (1.27) | 4.9 (1.19) | *1.31* |
| | | **4** | 6.0 (0.64) | 4.6 (0.62) | *1.62* | 4.8 (0.48) | 3.9 (0.46) | *1.32* | **9.5 (1.09)** | **6.3 (1.03)** | *2.12* |
| | | **7** | 6.2 (0.76) | 4.6 (0.74) | *1.47* | **4.5 (0.50)** | **3.3 (0.48)** | *1.73* | **10.1(1.17)** | **7.2 (1.10)** | *1.78* |
| | | **11** | 5.2 (1.04) | 4.5 (1.00) | 0.49 | 3.3 (0.69) | 2.9 (0.65) | 0.42 | 8.4 (1.50) | 7.8 (1.38) | 0.29 |
| | 2 | **1** | 4.0 (0.85) | 3.2 (0.83) | 0.69 | 3.6 (0.67) | 3.0 (0.64) | 0.63 | 5.1 (1.34) | 3.9 (1.28) | 0.66 |
| | | **4** | 4.8 (0.83) | 3.8 (0.81) | *0.88* | 3.0 (0.54) | 2.9 (0.52) | 0.14 | **10.4 (1.18)** | **7.2 (1.13)** | *1.94* |
| | | **7** | 5.1 (0.92) | 3.9 (0.91) | *0.94* | 2.9 (0.56) | 2.6 (0.55) | 0.37 | **11.5 (1.26)** | **7.6 (1.20)** | *2.2* |
| | | **11** | 4.7 (1.15) | 3.2 (1.14) | *0.95* | 3.3 (0.72) | 2.2 (0.72) | 1.1 | 6.3 (1.53) | 3.8 (1.47) | *1.19* |
| Entry-level only | 1 | **1** | 6.0 (2.21) | 5.4 (2.21) | 0.19 | 5.9 (1.70) | 5.6 (1.70) | 0.12 | 7.4 (2.62) | 4.3 (2.66) | *0.83* |
| | | **4** | 5.3 (2.19) | 5.7 (2.19) | 0.13 | 4.4 (1.65) | 5.5 (1.66) | 0.48 | 7.8 (2.47) | 5.7 (2.48) | 0.6 |
| | | **7** | 5.5 (2.20) | 5.7 (2.21) | 0.06 | 4.0 (1.66) | 5.1 (1.67) | 0.46 | 8.5 (2.51) | 6.5 (2.53) | 0.56 |
| | | **11** | 6.8 (2.26) | 5.2 (2.27) | 0.5 | 5.4 (1.72) | 4.3 (1.73) | 0.45 | 9.9 (2.65) | 6.7 (2.69) | *0.86* |
| | 2 | **1** | 2.7 (2.61) | 2.0 (2.62) | 0.19 | 2.4 (2.01) | 1.9 (2.02) | 0.18 | 4.0 (2.70) | 2.6 (2.72) | 0.37 |
| | | **4** | 3.0 (2.59) | 2.9 (2.60) | 0.03 | 1.8 (1.97) | 1.9 (1.98) | 0.04 | 5.8 (2.62) | 5.3 (2.63) | 0.14 |
| | | **7** | 3.8 (2.61) | 3.6 (2.61) | 0.05 | 2.1 (1.98) | 2.1 (1.99) | 0.0 | 6.9 (2.66) | 6.5 (2.67) | 0.11 |
| | | **11** | 5.8 (2.66) | 4.3 (2.66) | 0.4 | 3.9 (2.05) | 2.7 (2.04) | 0.42 | 7.5 (2.84) | 5.7 (2.82) | 0.45 |

Data reflect an aggregate predicted mean using mixed effect model (STATA®).
Bold-type denotes significant difference compared to control ($p < 0.05$).
Italics denotes effect size (ES; Cohen's d) >0.8 indicating large effect.
WoH = without helmet group.
All participants = analysis of all levels; season 1 n = 113 (WoH = 57, Control = 56) and season 2 n = 112 (WoH = 56, Control = 56).
Upper-level only = analysis of participants in 10th and 11th grades in season 1 (WoH = 37, Control = 34), advancing to 11th and 12th grades in season 2 (WoH = 36, Control = 34).
Entry-level only = analysis participants in 9th grade in season 1 (WoH = 20, Control = 22), advancing to 10th grade in season 2 (WoH n = 20, Control n = 22).
Week 1 = 1st week; occurring in pre-season and practices only schedule.
Week 4 = 4th week; occurring in first 1/3 of game schedule.
Week 7 = 7th week, occurring in middle 1/3 of game schedule.
Week 11 = 11th week, occurring in last 1/3 of game schedule.
[a] Indicate results derived from ANCOVA when mixed-model data did not converge.

In conclusion, this study provides evidence that tackling and blocking drills performed without a helmet reduces the frequency of head impacts among high school participants playing American football. The nature of significant findings and lack of evidence at the entry-level serves as an indicator that any tackling training purported to reduce head-first contact behavior should be verified through rigorous research and monitoring. Otherwise, coaches and players may be implementing techniques that fail to elicit a benefit. Future research is necessary on a broader scale to strengthen the findings herein and to better understand the dose-response relationship for helmetless training across all age and experience levels. While a significant reduction in head impact exposure is desirable, research should aim to establish the magnitude of the change necessary to achieve clinical relevance.

## Funding

This work was grant supported by the NineSigma Head Health Challenge 2 (Cleveland, OH). Study sponsors, National Football League, General Electric, and Under Armour®, had no role in the (1) study design; (2) the collection, analysis, and interpretation of data; (3) the writing of the report; or (4) the decision to submit the manuscript for publication.

## Disclosures

No honorarium, grant, or other form of payment was given to anyone to produce the manuscript. Authors ES, JM and SB wrote the first draft. Helmetless Tackling Training (HuTT®) is a registered trademark of the University of New Hampshire. The University of New Hampshire, not an individual, manages all license activities associated with HuTT®.

## Data statement

Data will be made available upon request.

## Acknowledgements

The authors wish to acknowledge the technical assistance contributions of Hanna Frantz, Matthew Nowak, Ashley Saracy, Erin Santuccio, Chantal Filiau, Rachel Springmann, Katelyn Metzger, Sean McDonnell, Scott James, Garrett Gillick, Kyle McAllister, and Dan Mayton.

## References

1. Broglio SP, Eckner JT, Martini D et al. Cumulative head impact burden in high school football. *J Neurotrauma* 2011; 28(10):2069–2078.
2. Kerr ZY, Collins CL, Mihalik JP et al. Impact locations and concussion outcomes in high school football player-to-player collisions. *Pediatrics* 2014; 134(3):489–496.
3. Kucera KL, Yau RK, Register-Mihalik J et al. Traumatic brain and spinal cord fatalities among high school and college football players — United States, 2005–2014. *MMWR Morb Mortal Wkly Rep* 2017; 65(52):1465–1469.
4. Brennan JH, Mitra B, Synnot A et al. Accelerometers for the assessment of concussion in male athletes: a systematic review and meta-analysis. *Sports Med* 2017; 47(3):469–478.
5. Broglio SP, Swartz EE, Crisco JJ et al. In vivo biomechanical measurements of a football player's C6 spine fracture. *N Engl J Med* 2011; 365(3):279–281.

6. Tagge CA, Fisher AM, Minaeva OV et al. Concussion, microvascular injury, and early tauopathy in young athletes after impact head injury and an impact concussion mouse model. *Brain* 2018; 141(2):422–458.
7. Slobounov SM, Walter A, Breiter HC et al. The effect of repetitive subconcussive collisions on brain integrity in collegiate football players over a single football season: a multi-modal neuroimaging study. *Neuroimage Clin* 2017; 14: 708–718.
8. Talavage TM, Nauman EA, Breedlove EL et al. Functionally-detected cognitive impairment in high school football players without clinically-diagnosed concussion. *J Neurotrauma* 2014; 31(4):327–338.
9. Wilde GJ. Risk homeostasis theory: an overview. *Inj Prev* 1998; 4(2):89–91.
10. Torg JS, Guille JT, Jaffe S. Injuries to the cervical spine in American football players. *J Bone Joint Surg Am* 2002; 84-A(1):112–122.
11. Viano DC, Halstead D. Change in size and impact performance of football helmets from the 1970s to 2010. *Ann Biomed Eng* 2012; 40(1):175–184.
12. King DA, Hume PA, Gissane C et al. Similar head impact acceleration measured using instrumented ear patches in a junior rugby union team during matches in comparison with other sports. *J Neurosurg Pediatr* 2016; 18(1): 65–72.
13. McIntosh AS, McCrory P. Effectiveness of headgear in a pilot study of under 15 rugby union football. *Br J Sports Med* 2001; 35(3):167–169.
14. Broglio SP, Martini D, Kasper L et al. Estimation of head impact exposure in high school football: implications for regulating contact practices. *Am J Sports Med* 2013; 41(12):2877–2884.
15. Keilman J. New tackling methods aim to make football safer, but proof still lacking, In: *Chicago Tribune.*, 2015.
16. Kerr ZY, Yeargin S, Valovich McLeod TC et al. Comprehensive coach education and practice contact restriction guidelines result in lower injury rates in youth American football. *Orthop J Sports Med* 2015; 3(7):2325967115594578.
17. Swartz EE, Broglio SP, Cook SB et al. Early results of a helmetless-tackling intervention to decrease head impacts in football players. *J Athl Train* 2015; 50(12):1219–1222.
18. Oeur RA, Karton C, Hoshizaki TB. Impact frequency validation of head impact sensor technology for use in sport. *34th international conference on biomechanics in sports* 2016.
19. Karton C, Oeur RA, Hoshizaki TB. Measurement accuracy of head impact monitoring sensor in sport. *34th international conference on biomechanics in sports* 2016.
20. O'Connor KL, Rowson S, Duma SM et al. Head-impact-measurement devices: a systematic review. *J Athl Train* 2017; 52(3):206–227.
21. Colley R, Connor Gorber S, Tremblay MS. Quality control and data reduction procedures for accelerometry-derived measures of physical activity. *Health Rep* 2010; 21(1):63–69.
22. Tukey J. The future of data analysis. *Ann Math Stat* 1962; 33(1):1–67.
23. Broglio SP, Williams RM, O'Connor KL et al. Football players' head-impact exposure after limiting of full-contact practices. *J Athl Train* 2016; 51(7):511–518.
24. Broglio SP, Sosnoff JJ, Shin S et al. Head impacts during high school football: a biomechanical assessment. *J Athl Train* 2009; 44(4):342–349.
25. Dompier TP, Kerr ZY, Marshall SW et al. Incidence of concussion during practice and games in youth, high school, and collegiate American football players. *JAMA Pediatr* 2015; 169(7):659–665.
26. Wegman E. Contextual interference effects on the acquisition and retention of fundamental motor skills. *Percept Mot Skills* 1999; 88(1):182–187.
27. Ericsson KA. Deliberate practice and acquisition of expert performance: a general overview. *Acad Emerg Med* 2008; 15(11):988–994.
28. Martini D, Eckner J, Kutcher J et al. Subconcussive head impact biomechanics: comparing differing offensive schemes. *Med Sci Sports Exerc* 2013; 45(4):755–761.
29. Tyson AM, Duma SM, Rowson S. Laboratory Evaluation of Low-Cost Wearable Sensors for Measuring Head Impacts in Sports. *J Appl Biomech* 2018; 34(4):320–326.
30. Cummiskey B, Schiffmiller D, Talavage TM et al. Reliability and accuracy of helmet-mounted and head-mounted devices used to measure head accelerations. *Proc Inst Mech Eng P J Sport Eng Technol* 2017; 231(2):144–153.
31. Campbell KR, Lynall RC, Luck JF et al. Impact detection rate analysis of four head impact sensors. *J Athl Train* 2016; 51(6). S-206.
32. Kontos AP. Perceived risk, risk taking, estimation of ability and injury among adolescent sport participants. *J Pediatr Psychol* 2004; 29(6):447–455.
33. Gamble T, Walker I. Wearing a bicycle helmet can increase risk taking and sensation seeking in adults. *Psychol Sci* 2016; 27(2):289–294.