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Influence of Adherence to a Helmetless-Tackling and -Blocking Training Intervention on Head-Impact Exposure Rates in Hawaiian High School Football

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Context: High school football remains a popular, physically demanding sport despite the known risks for acute brain and neck injury. Impacts to the head also raise concerns regarding their cumulative effects and long-term health consequences.

Objective: To examine the effectiveness of a helmetless-tackling training program to reduce head-impact exposure in high school football participants.

Design: A 3-year, quasi-experimental, prospective cohort study.

Setting: Public and private secondary schools with varsity and junior varsity football in the Honolulu, Hawaii, (Oahu, Hawaii) area.

Patients or Other Participants: A total of 496 football participants aged 14 to 18 years.

Intervention(s): Participants wore new football helmets furnished with head-impact sensor technology. Teams used a season-long (12-week) helmetless-tackling and -blocking intervention (Helmetless Tackling Training program) in years 2 and 3 consisting of a 3-phase systematic progression of 10 instructional drills.

Main Outcome Measure(s): Head impacts per athlete-exposure (ImpAEs), location of impacts, and head-impact burden per participant intervention adherence level (60% and 80%) and time (weeks).

Results: An overall regression analysis revealed a negative association between ImpAE and adherence ($P = .003$, $\beta = -1.21$, SE = 0.41). In year 3, a longitudinal analysis of weekly ImpAE data showed an overall difference between the adherent and nonadherent groups ($P = .04$ at 80%, $P = .004$ at 60%), mainly due to decreases in top and side impacts. Mean cumulative impact burden was less for the adherent (n = 131; $2105.84g \pm 219.76g$) than the nonadherent (n = 90; $3158.25g \pm 434.80g$; $P = .02$) group at the 60% adherence level.

Conclusions: Participants adhering to the intervention on at least a 60% level experienced a 34% to 37% reduction in the number of head impacts (per exposure) through the season. These results provide additional evidence that a helmetless-tackling and -blocking training intervention (using the Helmetless Tackling Training program) reduces head-impact exposure in high school football players. Adherence to an intervention is crucial for achieving intended outcomes.

Key Words: athletes, brain, neck injuries, prospective studies, outcome assessment

Key Points

- Participants adhering to the intervention on at least a 60% level experienced a 34% to 37% reduction in head impacts by the end of the season compared with those who did not.
- Football players who engaged in helmetless-tackling training at least 2 times per week were likely to benefit from fewer head impacts and the associated reduction in impact force burden (ie, gravitational acceleration).
- Adherence to any type of intervention, whether it be exercise, behavioral, or medical, is crucial for achieving intended outcomes.

High school football remains highly popular, with approximately 1 million participants across the United States in all versions of the sport (ie, 11-, 9-, 8-, and 6-player football).[1] American football is generally considered a collision sport, with a high incidence of injuries, including serious or catastrophic head or neck injuries.[2] In addition, football participants can sustain hundreds of head impacts in a season.[3–6] The cumulative effects (ie, burden) of these head impacts, whether having resulted in a concussion or not, are thought to be associated with long-term health consequences,[7–9] although not all research findings support this conclusion.[3,10]

To mitigate negative outcomes, a multitude of strategies have been developed and implemented with the aim of decreasing head-impact exposure in football. Whether through education, issuing of penalties or fines, or intervention and training techniques, these efforts typically focus on discouraging the behavior of initiating contact with the head when a participant executes a tackle or block skill.[11] Training football players in techniques for avoiding head impacts has been studied,[12–16] with some findings suggesting effectiveness, although study quality (ie, level of evidence) is generally low.[17] Accordingly, the recommendation of the National Athletic Trainers' Association is to "engage all stakeholders in the generation of high-level scientific research to test and validate strategies, techniques, or technologies proposed to support the reduction of head-impact exposure in football."[11] Given the potential for grave health consequences associated with head-first contact behavior, rigorous, high-level research is critical in understanding how to teach, train, and achieve mastery of contact skills, namely blocking and tackling, that reduces the risk for head impacts.

One high-level study conducted at the high school level involved a 2-year randomized, controlled trial testing the effectiveness of a helmetless-tackling behavioral intervention.[15] Research participants from 4 high school football programs underwent a season-long tackling training program performed without wearing helmets or shoulder pads during practice sessions. Coaches participated in a preseason clinic that provided on-field demonstrations of the prescribed helmetless drills complemented by a hard-copy manual and online video repository for use throughout the season. The authors reported decreased head-impact frequency during the midpoint of the season in those randomized to the helmetless-tackling training intervention. The same helmetless-tackling training intervention was conducted in a smaller sample at the collegiate level, and a decrease in head impacts in the treatment group was also reported.[14] The underlying theory supporting the effectiveness of the helmetless-training intervention lies in the concept of *risk compensation*, which is a change in behavior or an unintended shift in injury pattern derived from a new protective measure.[14,18,19] In football, this phenomenon is illustrated by the paradox of wearing a helmet, which allows for head-initiated contact because of the protection it affords, as it provides a false sense of security. The helmet is associated with the rise of catastrophic neck injuries due to spear-tackling behavior seen in football with the advent of the hard outer shell in the late 1950s.[20] Although rules introduced in the 1970s reduced the incidence of these injuries,[20] the rules themselves do not directly train or correct incorrect behavior proactively; they only provide a disincentive to exhibit the behavior. Anecdotally, the adoption of rugby-style tackling, which emphasizes avoidance of head-first tackling, has increased; however, to our knowledge, no other prospective research rooted in a helmetless-training concept exists, particularly as being deployed across an entire team versus being randomized to a smaller group within a team.[21]

Although results of research investigating the effectiveness of tackling training interventions for reducing head impacts or injury in football are promising, the dosage (ie, frequency, duration, and intensity) of the intervention prescription, and, more importantly, participant adherence to these interventions, are poorly described, if at all. In other words, to more fully understand whether a desired outcome is truly indicative of the actual response to the medical intervention, knowing the rate of actual completion of the treatment is essential. For example, the American Medical Association defines *adherence* as completion of at least 80% of a prescribed intervention.[22] A lower rate of adherence below a threshold would reduce one's ability to conclude the results, or intended benefit, was indeed due to the treatment. Adherence rates are not commonly reported in behavioral or exercise-intervention research. In exercise-intervention research that reported them, a 70% threshold was used.[23] In the helmetless-tackling training research cited above, adherence was not reported, yet a minimum 60% attendance to the intervention (prescribed at a rate of 1 or 2 times per week) was used as an inclusion criterion in analyzing the results.[14,15] Other researchers using techniques to decrease head impacts or injuries stemming from associated injury have poorly described the intervention implementation plan (ie, intention to treat [ITT]) or did not report the rate of adherence to the planned intervention itself.[13,16]

In early research of head-impact biomechanics in football, investigators initially measured and reported on various descriptive iterations of head-impact frequency, such as an overall season average.[24,25] Others have reported the accumulated burden by including measures of linear and rotational acceleration to better appreciate the potential amount of energy delivered to, and thus succumbed by, the brain over a period, such as a season or career.[6,8,10,26,27] For example, Broglio et al reported that high school athletes accumulated $>16\,000g$ of linear acceleration in a single season.[6] More recently, Zuidema et al reported physiological impairments in oculomotor function and elevations in blood biomarker levels with astrocyte activation and neuronal injury being associated with impact burden through a season.[8] Thus, exploring the effectiveness of a behavioral intervention for football tackling and blocking should include not only whether the number of head impacts are decreased but to what extent decreasing head impacts also mitigates the accumulating force burden over time.

Therefore, the purpose of this research was to study the effectiveness of a helmetless-tackling training program for reducing head-impact exposure in high school football participants. Head-impact exposure was expressed in terms of the frequency of head impacts (controlled by attendance), the impact location, and the accumulated burden (gravitational acceleration [g]) of these impacts at the end of the season. In addition, to more closely associate the intervention to the desired outcome of decreased head-impact exposure, we analyzed the data according to the rate of intervention adherence by participants (ie, intervention dose) to the ITT.

METHODS

Design

This study involved a quasi-experimental, prospective cohort design (Clinicaltrials.gov ID: NCT04020874).

Participants

Based on the original study plan, we set out to conduct our research over 3 successive football seasons starting in 2019, with the intervention commencing in 2020. The 2019 data were not analyzed or reported because they did not involve the intervention. Unfortunately, after year 1, the COVID-19 pandemic resulted in the cancellation of the 2020 season, creating a full year of inactivity between years 1 and 2 (2021). In addition, before year 2, one of the teams discontinued participation due to a small number of returning participants, full coaching staff turnover, and practice facility changes preventing adequate storage and maintenance of research equipment. We subsequently recruited an additional 3 teams (2 varsity, 1 junior varsity) from 2 new schools, with 1 school agreeing to commence the intervention and the other agreeing to an initial baseline year. Year 2 also involved an 8-week cessation of all public high school in-person activities including sports (August 4 through September 24), with sporadic daily interruptions in the private schools. Therefore, over a 3-year period, after approval by district and school administrators, participants were recruited from 4 high school football programs in the Honolulu, Hawaii, area. Year 1 (2019) served as a baseline season for participant and coach familiarization and piloting data collection, whereas years 2 and 3 (2021 and 2022, respectively) were planned for the implementation of the intervention. Programs included 2 public (Oahu Interscholastic Association) and 2 private (Interscholastic League of Honolulu) varsity (n = 4) and junior varsity (n = 2) teams representing grades 9 through 12. The nature of the research was explained to participants and legal guardians in group sessions and one-on-one conversations. The study was approved by the Institutional Review Board of the University of Hawai'i–Manoa, and all participants and their legal guardians provided written informed assent and consent, respectively.

Procedures

Each participant was sized and fitted by research personnel for a new Speedflex (Riddell, Inc) helmet per the manufacturer's fitting criteria. Helmets were furnished with an InSite Impact Response System (Riddell, Inc). The InSite System, which has been demonstrated as strongly correlated with Hybrid III acceleration data[28] and used previously in related studies,[27,29] records impact frequency, magnitude (*low*, 15–19*g*; *medium*, 20–28*g*; *high*, 29–43*g*; *alert*, 44–63*g*, and *high alert*, >63*g*), and location (front, top, back, and right and left sides). Researchers (D.B., K.G., I.L., and L.M.) monitored data capture, storage, and export to the Riddell InSite Training Tool, a password-secured proprietary cloud-based system.

A helmetless-tackling and -blocking behavioral intervention (Helmetless Tackling Training [HuTT]; University of New Hampshire) was deployed in years 2 and 3. The HuTT program consists of a 3-phase (ie, Static, Dynamic, Functional), systematic progression of 10 instructional drills performed without helmets and shoulder pads and is intended to develop and reinforce motor behaviors that explicitly remove the head as a point of contact. Intervention sessions lasted approximately 10 minutes and consisted of a prescribed set of 2 drills per session. Participants executed techniques against tackling bags or a padded shield held by teammates, alternating contact from the right and left directions. Based on previous research in which a treatment effect was shown, the intervention prescription was assigned at a frequency of 4 sessions per week during the preseason and 2 sessions per week during the competition season.[15] Sessions were held at the beginning or end of practice and monitored by research personnel (I.L., L.M., and D.B.).

The HuTT program was delivered to research participants by the team's respective coaching staff, who underwent standardized training before each of the 2 intervention seasons. At the outset, coaches underwent an onboarding process consisting of a web-based textual and video-formatted standard operating procedure, complemented with protocol videos and knowledge-check features (ie, quizlets; Retrieve Technologies). This was followed by virtual conference-call workshops with researchers (E.E.S., J.L.M., N.M., T.F., and R.O.) and an experienced coach consultant (not an author) on a team-by-team basis to answer questions specific to a coaching staff. Coaches were also provided an abbreviated field-side manual in the form of laminated pocket cards for quick reference. In year 3, the cessation of COVID-19 travel restrictions allowed for an intensive 3-hour, on-site training of coaches 2 months before the preseason by research personnel (E.E.S.) and experienced coach consultants (not authors) (average of 6 years using the HuTT program).

Research personnel (D.B., K.G., I.L., and L.M.) were present on-site during the season for quality control and field observation. The upcoming day's drills were reviewed before deployment, and participant intervention attendance (ie, adherence) was recorded. Detailed field notes included drill compliance (assigned drill number), drill sequencing, participant repetitions, appropriate use of field equipment, and removal of helmets and shoulder pads. Intervention adherence was calculated as a ratio of the number of treatments completed versus the number of treatments prescribed (ie, ITT) according to the original intervention plan (4 sessions/wk in the preseason and 2 sessions/wk in the regular season).

Daily attendance in a game or practice session, defined as entry into any training or game when the helmet was worn regardless of duration, was recorded as an athlete-exposure (AE). Time sequences of AEs were tracked and included start and stop times for the overall session as well as for pregame, quarters, and halftime of scrimmage and game sessions. Raw data were exported in aggregate and reviewed at various intervals throughout the season for quality control. Before final interpretation, these data were filtered for noise and spurious impacts using AE time sequences and attendance records.

Data were processed in spreadsheet format for corresponding head-impact frequency counts, gravitational acceleration levels, and impact location across each week of the season. Dependent variables included head impacts per AE (ImpAEs; head-impact frequency divided by attendance), location of impacts, and head-impact burden (sum of accumulated head-impact frequency per impact location and the assigned median gravitational acceleration level). Independent variables included grouping participants according to their adherence rate on 2 levels (80% and 60%) and time (in weeks).

Sample Size Determination and Statistical Analysis

When designing the study, we calculated sample size and power for the 2-sample *t* test for the mean differences in ImpAEs between hypothetical treatment and control groups. With a sample size of 100 (50 each in the treatment and control groups) and a mean difference of 1.2 and the SE of 2.0, such tests yielded a power of 84%. Power calculations were conducted using PROC POWER in SAS (version 9.4; SAS, Cary, NC).

Linear regression was used to test for associations between ImpAEs and adherence to the intervention. This was followed by an analysis of longitudinal data over time (week) of ImpAEs using a linear mixed-effects model with adherence and time effects (fixed effects), accounting for random effect of time within participants. The weekly ImpAEs were also evaluated using false discovery rate–corrected *t* tests at each week. Finally, an analysis of variance was used to compare adherent and nonadherent groups ($\alpha = .05$; reported mean $\pm$ SE) for overall ImpAEs, location of impacts, and cumulative head-impact burden at the conclusion of the study in year 3. Statistical analysis of data was performed using R software (version 4.1.0; R Core Team, 2021).

RESULTS

Sample

We enrolled a total of 496 unique participants (494 male, 2 female) over 3 years. Of this total, 154 athletes participated for >1 year, and 19 athletes participated all 3 years, resulting in 650 participant-seasons. This sample exceeded our original a priori estimated sample size. Attrition resulted from a combination of factors, such as graduation, departing team for personal reasons, and season-ending injury. New participant recruitment between years was intended to replace the expected attrition over time. A total of 42 participants and their respective data were excluded due to incomplete enrollment paperwork or demonstrated equipment failure. The final analysis involved organizing participant data into adherent or nonadherent groups at the 60% and 80% adherence threshold levels, resulting in different sample sizes for each category and year the intervention was deployed (Figure 1A through D).

A

			No. of Participants/Team				
Year	No. of Participants	Team	Total	Freshman	Sophomore	Junior	Senior
1	178	A	48	3	10	24	11
		C	60	2	12	27	19
		D	70	27	43	0	0

			No. of Participants/Team				
Year	No. of Participants	Team	Total	Freshman	Sophomore	Junior	Senior
2	241	B[a,b]	42	0	6	11	25
		C[b]	73	9	12	29	23
		D[b]	56	38	17	1	0
		E	42	3	7	19	13
		F	28	11	17	0	0

			No. of Participants/Team				
Year	No. of Participants	Team[c]	Total	Freshman	Sophomore	Junior	Senior
3	231	B	39	5	7	16	11
		C	57	2	12	17	26
		D	51	11	32	5	3
		E	52	0	9	24	19
		F	32	23	9	0	0

B

		Participant Years in Study		
Year	No. of Participants	First	Second	Third
1	178	178	NA	NA
2[d]	241	199	42	NA
3	231	119	93	19

C

		Class			
Year	No. of Participants	Freshman	Sophomore	Junior	Senior
1	7	7	0	0	0
2	25	6	19	0	0
3	10	0	10	0	0

D

				Participants, n (%)		
Year	Threshold	Group	Total	Offense	Defense	Special Teams
2	60%	Adherence	28	13 (46)	15 (54)	0 (0)
		Nonadherence	124	50 (40)	72 (58)	2 (2)
	80%	Adherence	19	11 (58)	8 (42)	0 (0)
		Nonadherence	133	52 (39)	79 (59)	2 (2)
3	60%	Adherence	131	72 (55)	57 (44)	2 (1)
		Nonadherence	90	44 (49)	44 (49)	2 (2)
	80%	Adherence	66	40 (61)	24 (36)	2 (3)
		Nonadherence	155	76 (49)	77 (50)	2 (1)

Figure 1. Consolidated Standards of Reporting Trials flow diagram across 3 football seasons, years 1–3 (2019, 2021, and 2022), with participants from a total of 6 teams. Data from year 1 are not reported in this paper. A, Baseline: head-impact biomechanical data collected without the intervention. B, Participant summary. C, Data exclusions. D, Adherence. [a] Team B replaced Team A. [b] Intervention: Helmetless Tackling Training (HuTT) program applied at team level. [c] All teams applied the HuTT program. [d] The season between years 1 and 2 was cancelled due to COVID-19. Abbreviation: NA, not applicable.

Association Between Level of Adherence and Impacts

An overall regression analysis revealed a negative association between ImpAE and adherence ($P = .003$, $\beta = -1.21$, SE $= 0.41$), suggesting that the more adherent participants were, the fewer ImpAEs the participants sustained. From the regression analysis of ImpAE on raw adherence, a negative association was found between ImpAE and adherence during year 2 ($P = .01$, $\beta = -1.43$, SE $= 0.55$) and a stronger negative association was found in year 3 ($P < .001$, $\beta = -2.26$, SE $= 0.66$) (Figure 2).

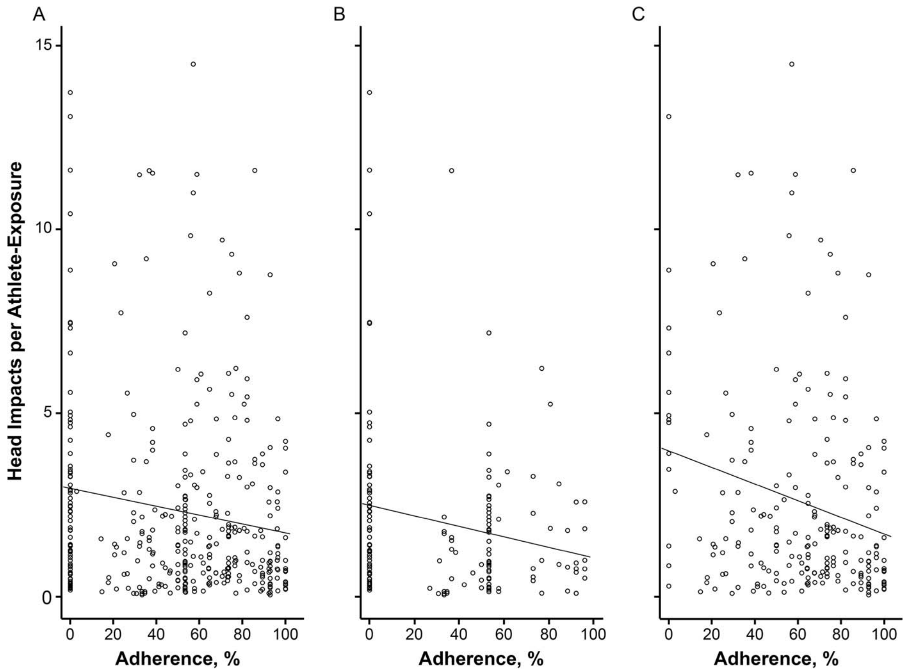

Figure 2. Regression plots for adherence and head impacts per athlete-exposure. A. Overall combined data from years 2 and 3. B. Year 2 only. C. Year 3 only.

Effect of the Intervention Over Time

When the intervention began in year 2, ImpAE comparisons between adherent and nonadherent groups were similar in weeks 1 through 4 (difference in mean ImpAEs = 0.139, $P = .93$ at 80%; difference in mean ImpAEs = 0.093, $P = .93$ at 60%). Starting in week 5, the 2 public schools' seasons were paused due to COVID-19, while the 2 private schools continued, albeit with variable interruptions. Thus, the nonadherent group had fewer ImpAEs than the adherent group at the 60% level (difference in mean ImpAEs = −1.34, $P < .001$), yet the season and pace with the intervention were no longer synchronized, negating further comparisons of intervention effects over time (Figure 3).

In year 3, the longitudinal analysis of weekly ImpAE data showed a pattern of separation and overall difference between the adherent and nonadherent groups ($P = .040$ at 80%, $P = .004$ at 60%) as well as a decrease of ImpAEs over time ($P = .04$ at both 80% and 60%). The further analysis of week-by-week data revealed fewer ImpAEs for the adherent than for the nonadherent group in multiple weeks at both the 80% and 60% thresholds (Figure 4).

Overall Group Comparisons at Study Completion

The comparison of adherent and nonadherent groups by aggregate total of ImpAEs showed that the 80% adherent group experienced fewer ImpAEs (n = 66; 1.88 ± 0.28) than the nonadherent group (n = 155; 2.84 ± 0.24; $P = .02$) (Figure 5A). Similarly, the 60% adherent group had fewer ImpAEs (n = 131; 2.06 ± 0.20) than the nonadherent group (n = 90; 3.26 ± 0.35; $P = .002$) (Figure 5B).

These ImpAEs were spread across the 4 locations of the helmet (front, top, side [left and right], and back). The comparison between groups of ImpAEs per location showed that the adherent group experienced fewer ImpAEs than the nonadherent group at the top and sides of the helmet at both the 80% and 60% levels (Table).

Overall cumulative impact burden also showed that the 60% adherent group (n = 131; 2105.84*g* ± 219.76*g*) sustained less force over the season when compared with the nonadherent group (n = 90; 3158.25*g* ± 434.80*g*; $P = .02$).

The mean cumulative impact burden each player experienced with just front, top, and side locations combined showed the adherent group (n = 131; 2105.84*g* ± 219.76*g*) sustained less cumulative impact burden than the nonadherent group (n = 90; 3158.25*g* ± 434.80*g*; $P = .02$) at the 60% adherence level. Distribution of cumulative impact burden by location showed no difference between adherent and nonadherent groups at either level when combining only front and top locations. However, when analyzing only side impacts, we observed that the 80% adherent group experienced less force burden (n = 66; 634.52*g* ± 98.32*g*) compared with the nonadherent group (n = 155; 1220.40*g* ± 249.23*g*; $P = .02$). The 60% adherent group also had less force burden (n = 131; 827.99*g* ± 98.32*g*) than the nonadherent group (n = 90; 1361.94*g* ± 249.23*g*; $P = .03$) (Figure 6).

DISCUSSION

This study provides additional evidence that a helmetless-tackling and -blocking training intervention using the HuTT program reduces head-impact exposure in high school football players. Our most important finding was that participants who adhered to the intervention on at least a 60% level experienced a 34% to 37% reduction in ImpAEs by the end of the season. In practical terms and over a season comprising at least 58 exposures (practices and games), this result equates to 56 to 70 fewer impacts to the head and a 33% reduction (1053*g*) in impact magnitude by the end of the season. Thus, football players who engaged in helmetless-

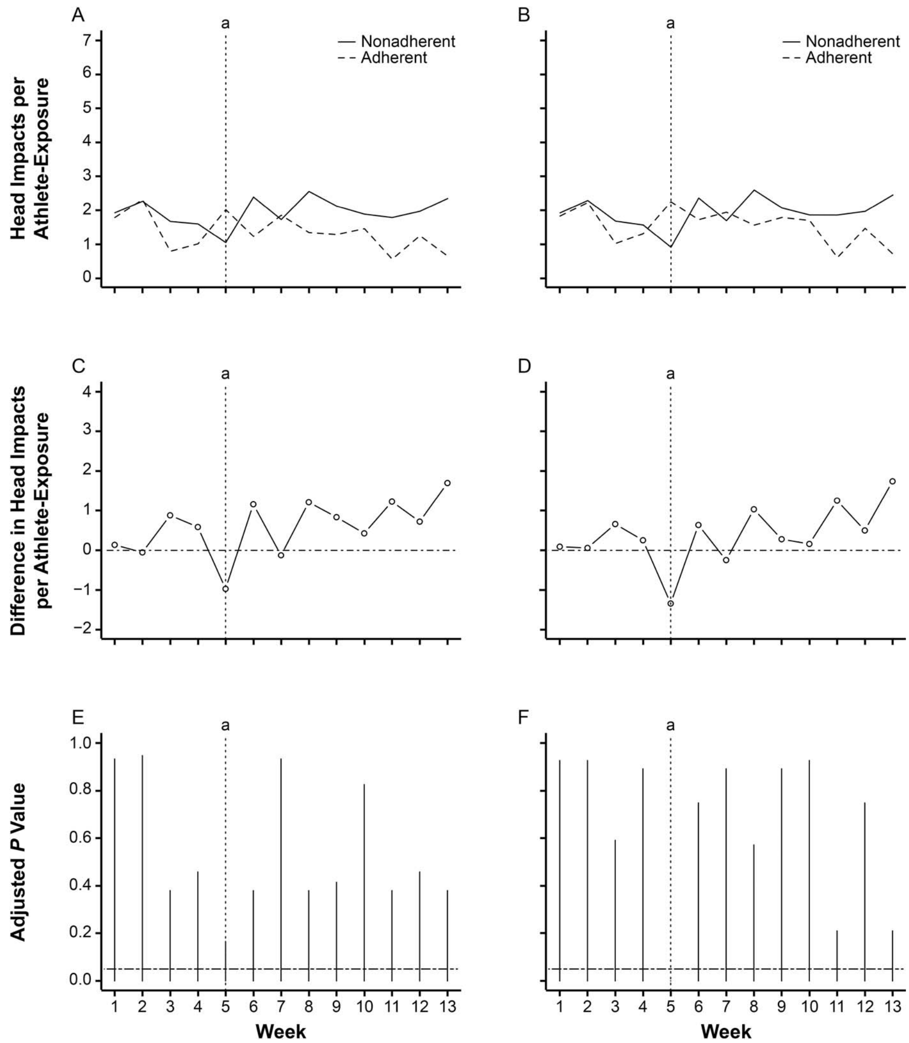

Figure 3. Effect of the intervention over time for year 2. Weekly head impacts per athlete-exposure (ImpAEs) used for linear mixed-effects model comparison between adherent and nonadherent groups at A, 80%, and B, 60% adherence levels. Mean difference between groups at C, 80%, and D, 60% adherence levels. False discovery rate–corrected *t* test *P* values at each week at E, 80%, and F, 60% adherence levels. Horizontal dotted line indicates threshold of 0.05. The nonadherent group had fewer ImpAEs than the adherent group at week 5. [a] Vertical dotted line indicates time when 2 public school teams resumed the season after an 8-week pause due to COVID-19.

tackling training at a frequency of at least 2 times per week were likely to benefit from fewer head impacts and the associated reduction in impact force (ie, gravitational acceleration) burden.

The data were analyzed according to 2 levels of adherence, and the results merit careful interpretation. Specifically, differences between the adherent and nonadherent groups were typically stronger at the 60% than the 80% level, both numerically and statistically, yet this finding should not be interpreted to mean that fewer exposures to the treatment led to a stronger outcome. Rather, the reason for these differences was most likely that the lower threshold level (60%) had a larger sample size because more participants met the criteria for the lower than the higher (80%) threshold level. Nagpal et al described 4 possible scenarios for interpreting exercise intervention studies based on variations in adherence levels and outcomes.[23] Although the scenarios typically involve comparisons between treatment and control groups, the authors suggested that results of single studies, such as our study, and fitting any scenario should be interpreted with caution because confounding variables (eg, population characteristics and study environment) that can influence adherence or the outcome may be present. This suggests that evaluating the effect of an intervention on health outcomes should arise from the context of systematic reviews that synthesize similar study designs.

Two previous studies and now our study have tested the effectiveness of a helmetless-tackling training technique across various populations and environments, and each has shown positive outcomes from the intervention.[14,15] The first investigation expressly testing the effectiveness of a helmetless-tackling intervention was conducted in a single collegiate sample.[14] A total of 25 participants were randomized on the individual level within the team to undergo the helmetless-tackling training program twice in the preseason and only once in the regular season. The treatment group experienced fewer ImpAEs compared with the control group as well as the preseason level of ImpAEs. On the high school level in the second study, participants were again

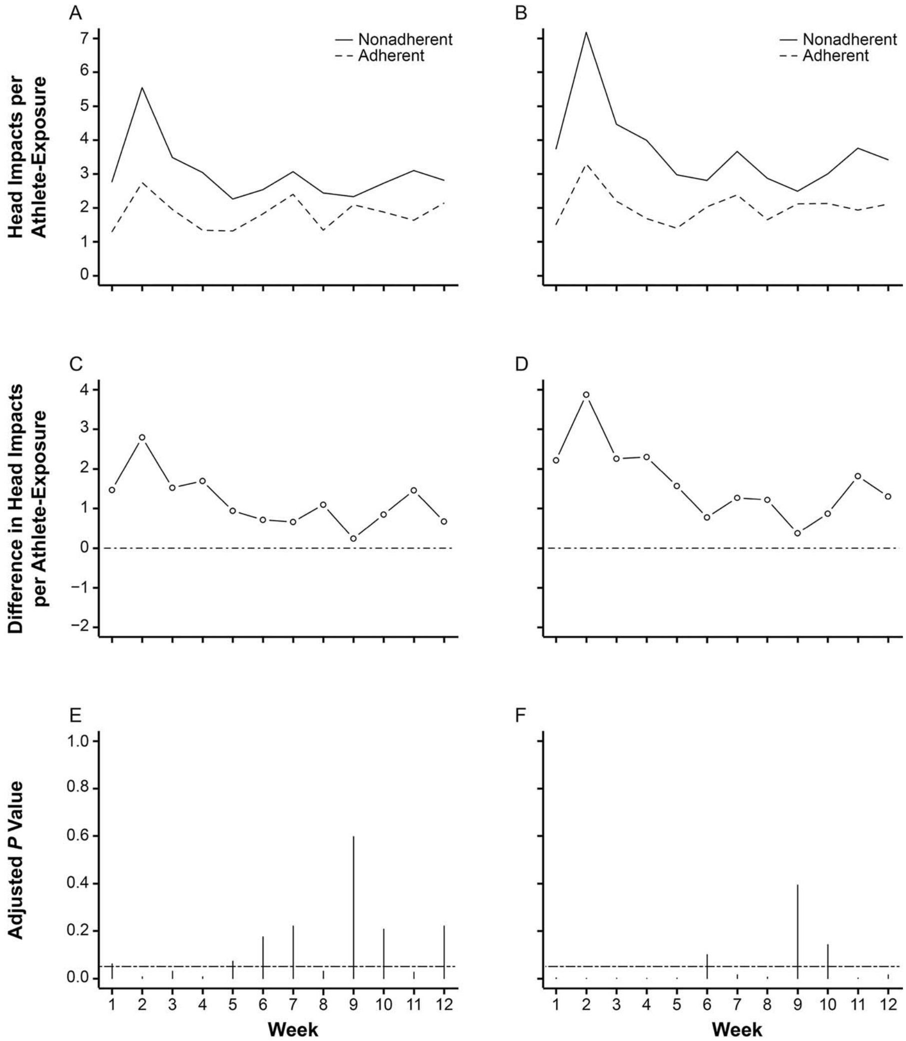

Figure 4. Effect of the intervention over time for year 3. Weekly head impacts per athlete-exposure (ImpAEs) used for linear mixed-effects model comparison between adherent and nonadherent groups at A, 80%, and B, 60% adherence levels. Mean difference between groups at C, 80%, and D, 60% adherence levels. False discovery rate–corrected *t* test *P* values at each week at E, 80%, and F, 60% adherence levels. Horizontal dotted line indicates threshold of 0.05. The adherent group had fewer ImpAEs than the nonadherent group in weeks 2, 4, 8, and 11 when grouped at the 80% adherence level and all weeks except 6, 9, and 10 when analyzed at the 60% level.

randomized and within 4 different teams.[15] Results from that 2-year study showed the treatment group experienced fewer ImpAEs compared with the control group but only during the midpoint of the season. In other words, although the groups were similar at the preseason, their ImpAEs separated during the midseason but returned to being similar toward the end of the season. We are the first to test the effectiveness of the helmetless-tackling training program across an entire team, with grouping according to variable levels of adherence as opposed to a true control sample. The ability to effect, and statistically detect, a change given the relatively narrow overall impact-per-exposure margin in our sample is encouraging. In the previous research exploring the effectiveness of a helmetless-tackling intervention, control participants on the high school level experienced nearly 6 ImpAEs, depending on the week of the season, with 10 ImpAEs during games.[15] In the smaller collegiate sample, control participants averaged almost 14 ImpAEs.[14] However, in our study, nonadherent participants experienced only around 2 to 3 ImpAEs.

Not only should the overall frequency of impacts sustained by high school football players during play be appreciated but also the magnitude (eg, acceleration) that these impacts entail. Researchers are increasingly focused on the accumulated burden that these impacts impart to the human brain over time and the potential for neurological consequences.[10,27,30] Participants in our study who were adherent to the intervention not only had fewer ImpAEs but also experienced less accumulated force burden over time. Extrapolated over a 4-year high school career, the magnitude of this outcome of potentially thousands fewer gravitational acceleration units directed to the brain is substantial.[31]

Relatedly, focusing on the areas of the helmet most associated with the behavior of leading with the head (ie, top, front, and sides), that the decrease in head impacts was driven by decreases in impacts to the top and side of the helmet (as opposed to if they had been to the back of the helmet) is encouraging.[11] Future research should be done to help further elucidate whether the benefits of the training come not only in

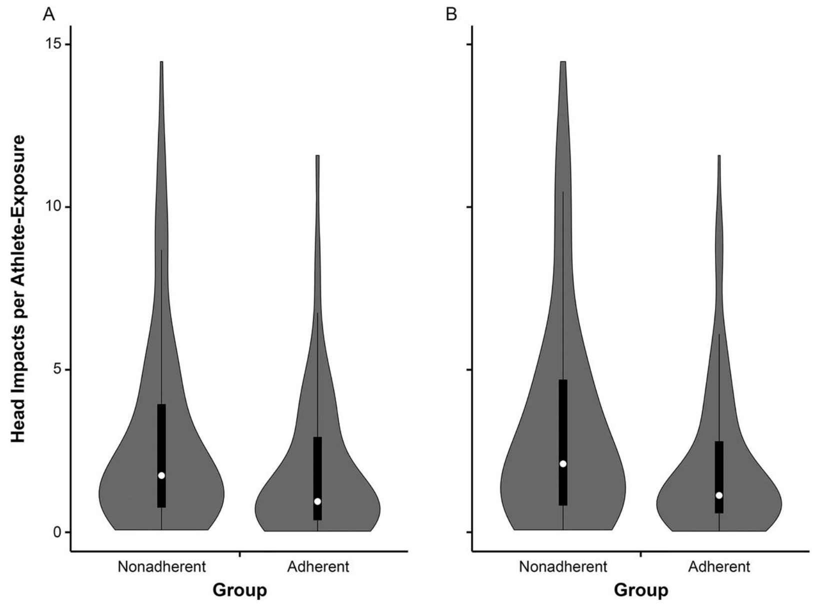

Figure 5. Mean head impacts per athlete-exposure (ImpAEs) in final season (year 3). A, 80% adherence level. The adherent group had fewer ImpAEs than the nonadherent group ($P = .02$). B, 60% adherence level. The adherent group had fewer ImpAEs than the nonadherent group ($P = .002$).

reducing overall impacts to the head but also in shifting impacts away from the top and front of the helmet.

The data reported herein were collected during unexpected challenges from the COVID-19 pandemic that directly affected the fluidity of our intended research, as others involved in clinical-intervention–based studies have reported.[32] For example, faced with an inability to conduct an in-person training before 2021 (year 2) as we had intended, we pivoted to using virtual platforms to communicate with coaches and educate them about the intervention season.[33] Although using such technology was necessary and allowed us to initiate the intervention that year, coach onboarding and subsequent intervention deployment was disadvantaged at the same time. Relatedly, unanticipated variation occurred in coach compliance in year 2, in contrast to previous research in which teams were fully compliant.[14,15] In fact, one of our teams allowed individual positional coaches to carry out the intervention with their assigned skill group and on their own weekly schedule, leading to a variable dosing pattern and subsequent player adherence rates. Participant-related issues were also a factor associated with the interruption due to the pandemic. The increase in community infection rates triggered a return to remote learning for public schools and an 8-week suspension of interscholastic sports. Whatever was gained in consistency for research participants across teams was disrupted due to the priorities of public health administration during the pandemic. Finally, returning to sports participation also required proof of vaccination for participants, which introduced variation in overall attendance as well as with the intervention. In year 3, however, we were able to carry out the in-person training with an initial training and onboarding clinic held approximately 2 months in advance of the preseason, allowing for more time for coaches to plan for implementation of the intervention. This no doubt contributed to the stronger findings and statistical differences in our variables of interest in the final year.

In conclusion, further research is needed to better understand what intervention (drill type and technique) and player characteristics (age, maturation, and experience), as well as intervention dosing (frequency, duration, and intensity) should be used to garner the strongest response, whether across a full team or specific to an individual player. Ultimately, the association with decreasing head-impact behavior and improved clinical outcomes based on rigorous study design is critically needed to protect and promote lifetime participation in sports or recreational endeavors.

Table. Head-Impact Frequency per Athlete-Exposure by Location

	Impact Frequency per Athlete-Exposure, Mean ± SE					
	80% Level			60% Level		
Location	Adherent Group	Nonadherent Group	*P* Value	Adherent Group	Nonadherent Group	*P* Value
Total	1.88 ± 0.28	2.84 ± 0.24	.02[a]	2.06 ± 0.19	3.26 ± 0.35	.002[a]
Front	0.78 ± 0.17	0.63 ± 0.08	.37	0.59 ± 0.10	0.80 ± 0.13	.20
Top	0.29 ± 0.06	0.83 ± 0.11	.002[a]	0.50 ± 0.08	0.92 ± 0.16	.01[a]
Sides	0.54 ± 0.10	1.14 ± 0.13	.004[a]	0.72 ± 0.09	1.31 ± 0.20	.003[a]
Back	0.27 ± 0.05	0.20 ± 0.02	.21	0.24 ± 0.03	0.19 ± 0.03	.28

[a] Indicates fewer impact frequencies per athlete-exposure between adherent and nonadherent groups.

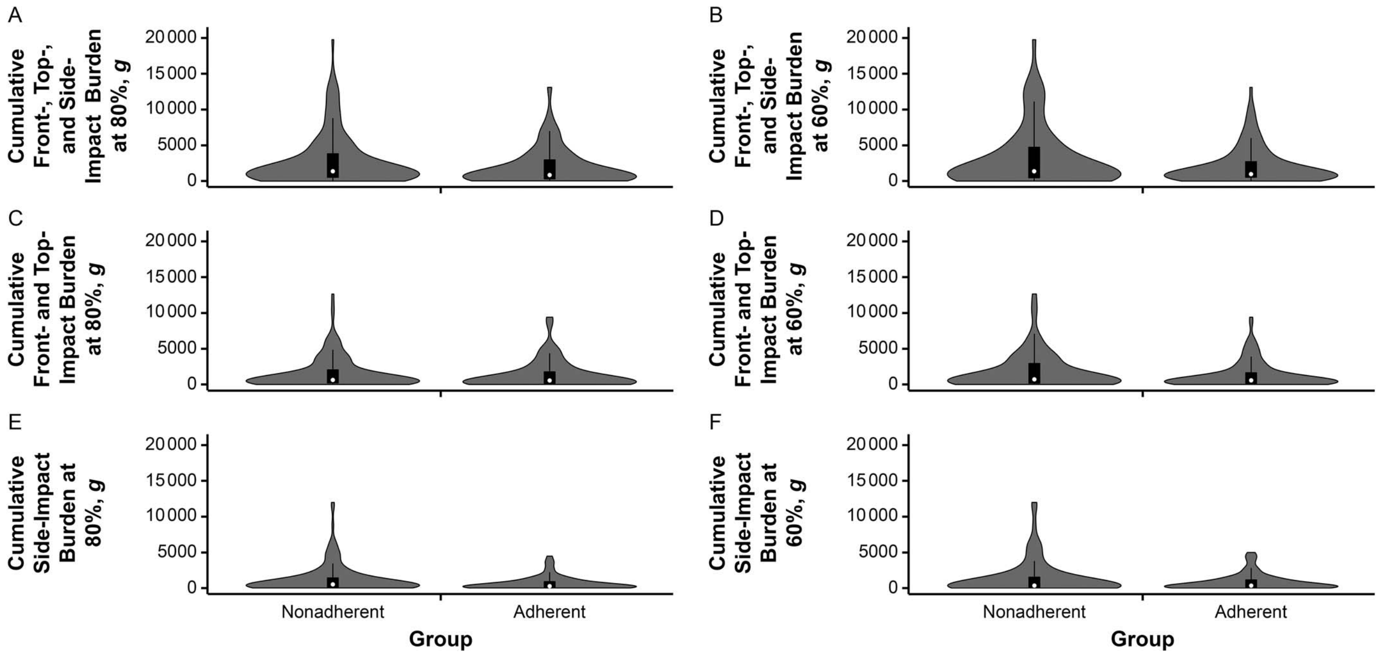

Figure 6. Mean cumulative head-impact burden in final season (year 3). A, Front, top, and side impacts combined at the 80% adherence level. B, Front, top, and side impacts combined at the 60% adherence level. The adherent group sustained less cumulative impact burden than the nonadherent group (*P* = .02). Top and side impacts only at C, 80%, and D, 60% adherence levels. E, Side impacts only at the 80% adherence level. The adherent group had less cumulative impact burden than the nonadherent group (*P* = .02). F, Side impacts only at the 60% adherence level. The adherent group had less cumulative impact burden than the nonadherent group (*P* = .03).

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