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Preliminary Examination of Guardian Cap Head Impact Kinematics Using Instrumented Mouthguards

Kristen G. Quigley, BS*; Dustin Hopfe, MS, LAT, ATC*; Madison Fenner, BS*; Philip Pavilionis, MS, ATC*; Vincentia Owusu-Amankonah*; Arthur Islas, MD†; Nicholas G. Murray, PhD*

*Neuromechanics Laboratory, School of Public Health, and †School of Medicine, University of Nevada, Reno

Context: Guardian Caps (GCs) are currently the most popular external helmet add-on designed to reduce the magnitude of head impacts experienced by American football players. Guardian Caps have been endorsed by influential professional organizations; however, few studies evaluating their efficiency are publicly available.

Objective: To present preliminary on-field head kinematics data for National Collegiate Athletic Association (NCAA) Division I American football players using instrumented mouthguards through closely matched preseason workouts with and without GCs.

Design: Case series.

Setting: The 2022 American football preseason.

Patients or Other Participants: Twenty-five male NCAA Division I student-athletes participating in American football completed some portion of the 6 workouts included in this study. Of the 25 participants, 7 completed all 6 workouts using their instrumented mouthguards.

Main Outcome Measure(s): Peak linear acceleration (PLA), peak angular acceleration (PAA), and total impacts were collected via instrumented mouthguards during 3 preseason workouts using traditional helmets (TRAD condition) and 3 using a TRAD and GCs (GC condition). The TRAD and GC values for PLA, PAA, and total impacts were evaluated using analyses of variance.

Results: No difference was present between the collapsed mean values for the entire sample between the TRAD and GC conditions for PLA (TRAD = 16.3g ± 2.0g, GC = 17.2g ± 3.3g, P = .20), PAA (TRAD = 992.1 ± 209.2 rad/s^2, GC = 1029.4 ± 261.1 rad/s^2, P = .51), or the total number of impacts (TRAD = 9.3 ± 4.7, GC = 9.7 ± 5.7, P = .72). Similarly, no difference was observed between the TRAD and GC conditions for PLA (TRAD = 16.1g ± 1.2g, GC = 17.2g ± 2.79g, P = .32), PAA (TRAD = 951.2 ± 95.4 rad/s^2, GC = 1038.0 ± 166.8 rad/s^2, P = .29), or total impacts (TRAD = 9.6 ± 4.2, GC = 9.7 ± 5.04, P = .32) between sessions for the 7 players who completed all 6 workouts.

Conclusions: These data suggested no difference in head kinematics data (PLA, PAA, and total impacts) when GCs were worn. Therefore, GCs may not be effective in reducing the magnitude of head impacts experienced by NCAA Division I American football players.

Key Words: concussion, helmets, student-athletes, traumatic brain injury

Key Points

- Peak angular acceleration, peak linear acceleration, and total impacts did not differ between the traditional helmet and Guardian Cap conditions.
- Our results suggest that Guardian Caps may not be effective in reducing the peak angular acceleration, peak linear acceleration, and total impacts experienced by American football players.

Brain injuries have been closely studied in recent years, with a particular emphasis on sport-related concussion (SRC). They remain a vital public health concern that affect participants of all ages and at all levels of sport. For collegiate athletes specifically, SRC represents approximately 6% of all athletic injuries, with American football serving as the largest contributor to this statistic.[1] In addition to these head injuries, many athletes experience a phenomenon known as *repetitive head impacts* (RHIs), which are defined as multiple blows to the head that are not significant enough to result in the clinical diagnosis of a concussion or to generate symptoms.[2] Repetitive head impacts are particularly common among American football players due to the repetitive blows incurred on each subsequent play for most players, and RHIs have been hypothesized to have a cumulative effect on the brain.[2] Previous authors have suggested that frequent exposure to RHIs may lead to changes in white matter connectivity and decreased activation of the dorsolateral prefrontal cortex, which is the brain area primarily responsible for executive function and decision-making.[2–4] This combination of factors presents a clear need for interventions to better protect athletes in all sports and at all levels of participation, with a particular emphasis on American football players.

Research on American football has resulted in many positive innovations over the years, particularly with the implementation of instrumented mouthguards (iMGs) to collect data regarding changes in rotational and linear kinematics. Instrumented mouthguards can be difficult to use because athletes must be gentle with the hardware (eg, avoiding chewing while wearing the iMG); however, they provide a considerable advance and supply data comparable with those of traditional helmet-based systems.[5] When used properly with a custom dental scan for fitting and routine maintenance, iMGs can measure the number of impacts each user experiences during the recording session; that said, best scientific practices indicate the need for advanced filtering techniques and substantial video verification, which limit the immediate on-field applications. However, iMGs provide a comfortable and affordable way to accurately track head impacts to aid investigators in answering critical questions about preventive approaches for SRC and RHIs.

One possible course of action to better protect American football players from the effects of RHIs or SRC is to improve helmet technology. Though RHI research is relatively new, for years researchers have been attempting to create helmets that better attenuate the forces applied to the head. The push for better helmet designs can involve altering the shell or inner padding or adding padding to the exterior of the existing helmet.[6] One of the first innovations of this kind was the ProCap (Protective Sports Equipment Inc), which was released in 1989 and consisted of a hard-shell cover that was affixed to the exterior of a traditional football helmet.[6] ProCap was endorsed by some American football players in the National Football League (NFL); yet the ProCap's popularity dwindled when the primary NFL helmet manufacturer at that time, Riddell, revoked the certification from its helmets that had been modified with a ProCap.[6]

In 2011, the National Operating Committee on Standards for Athletic Equipment (NOCSAE) backed Riddell's decision from years prior, stating that the addition of components to athletic equipment or modification of the original equipment voided the warranty and safety certifications of the product.[6] This regulation was later revisited by NOCSAE and overturned, so long as the company wishing to design helmet add-ons tested the product itself and became responsible for the warranty of the equipment.[7] This change in legal proceedings allowed the current market leader, Guardian Sports, to create the Guardian Cap (GC) in 2015.

The GC is currently the most popular external helmet add-on aimed at attenuating the magnitude of head impacts experienced by American football players. The GC has a similar design to the previously mentioned ProCap, but it is classified as a soft-shell cover.[8] The GC's popularity is in part due to heavy endorsement by the NFL, which used GCs during its 2022 preseason training. The NFL described a 50% reduction in SRC when compared with the averages from 2018, 2019, and 2021; nonetheless, the data behind this claim have never been published.[9] Other authors have tested the effectiveness of the GC; however, most of these studies used only laboratory helmet impact testing, such as vertical drop testing.[10] On-field measurements have been provided in a single study to date; its authors used iMGs to collect angular and rotational head kinematics from 5 National Collegiate Athletic Association (NCAA) Division I American football players.[11] On-field data were obtained in 2019 during 13 workouts from 5 linebackers wearing traditional helmets and compared with on-field data obtained in 2021 during 14 workouts from a unique set of 5 linebackers wearing GCs.[11] Although prior research is sparse, the results suggested that the GC did not alter or reduce head kinematics, but additional data are needed from a larger cohort spanning multiple positions to confirm these findings.

To address the endorsement from the NFL and the need for larger on-field data validations, our aim was to establish preliminary angular and rotational head kinematics data for NCAA Division I American football players through closely matched practice sessions with and without GCs. Consistent with the limited previous literature, we hypothesized that GCs would not reduce the peak linear acceleration (PLA) or peak angular acceleration (PAA) experienced by American football players during preseason workouts.

METHODS

Participants

Twenty-five NCAA Division I male American football players (average age = 20 ± 1 years) were recruited from the same American football team if they wore dental-scanned and -fitted iMGs to record head impacts (3200 Hz; Prevent Biometrics) during preseason workouts. Each iMG contained a triaxial accelerometer and gyroscope to measure linear and rotational kinematics. The players wore the iMGs for various numbers of the 6 workouts included in this study. For example, 13 players had valid data from their iMGs for the first workout included, whereas 17 did for the third workout (Table 1). Of the 25 participants, only 7 players (average age = 20 ± 0.76 years) engaged in all 6 practice sessions and had complete data for all recorded workouts (Table 1). Due to the fluctuating sample size for each workout, we analyzed these data in 2 ways. The first analysis used all available data from the full set of 25 participants, resulting in 83 individual observations, as some of the 25 participants completed multiple workouts. The 7 players with valid data from all 6 workouts underwent a second, separate repeated-measures analysis. The football players' positions varied (offensive lineman, defensive lineman, running back, tight end, and linebacker), but all were identified by the coaching staff as having the potential to be high-dose players (Table 1). We defined a *high-dose player* as an individual who had the greatest opportunity for contact based on the position type and the offensive/defensive scheme of the respective university. This included players in positions such as offensive lineman, defensive lineman, running back, tight end, and linebacker, as players in these positions are known to receive more impacts per training week and are thus more susceptible to the effects of RHIs compared with quarterbacks, kickers, or punters.[12] Identification of high-dose players occurred through close consultation with the coaching and sports medicine staff. Of the 25 participants, 12% (n = 3) of the athletes were starters, 36% (n = 9) were rotational players, and 52% (n = 13) were scout team players as denoted by the coaching staff (Table 1). The players were allowed to choose the brand of their traditional helmet; 84% (n = 21) of players wore the Riddell SpeedFlex (Riddell Sports Group), 4% (n = 1) wore the Vicis Zero2, and 12% (n = 3) wore the Schutt F7 2.0 (Schutt Sports). The players used the same helmet for each of the 6 recorded workouts.

Participants were excluded if they did not adhere to the iMG compliance standards (eg, chewed excessively) or if they had an injury that precluded them from practicing on the day of the selected practices. Of the 25 participants, 2 had been diagnosed with a concussion within 6 months of the study start date but were medically cleared to return to sport. One participant was diagnosed with a concussion during the study and was then excluded. Concussion history was not an exclusion criterion; however, all participants needed to complete the full workout as designated by the coaching staff.

Table 1. Participant Demographics for the Entire Sample and the 7 Consistent Players at Each Practice Time Point

	Practice No.					
	Traditional Helmets			Guardian Caps		
	1	2	3	1	2	3
	Full Sample (n = 25)					
Participants, No.	13	12	17	14	14	13
Average age, mean ± SD, y	20 ± 1.19	20 ± 0.72	20 ± 1.73	20 ± 1.25	20 ± 1.08	20 ± 1.27
	No. (%)					
Position						
OL	3 (23.08)	2 (15.38)	2 (11.76)	2 (14.28)	3 (21.43)	3 (23.08)
DL	2 (15.38)	1 (8.33)	2 (11.76)	1 (7.14)	2 (14.28)	2 (15.38)
RB	2 (15.38)	1 (8.33)	3 (17.65)	3 (21.43)	3 (21.43)	2 (15.38)
TE	3 (23.08)	2 (15.38)	3 (17.65)	2 (14.28)	1 (7.14)	3 (23.08)
LB	3 (23.08)	6 (50.00)	7 (41.78)	6 (42.86)	5 (35.71)	3 (23.08)
Starter status						
Rotational	4 (30.77)	6 (50.00)	7 (41.18)	6 (42.86)	7 (50.00)	4 (30.77)
Nonstarter	7 (53.85)	6 (50.00)	9 (52.94)	8 (57.14)	6 (42.86)	7 (53.85)
Starter	2 (15.38)	0 (0.00)	1 (5.88)	0 (0.00)	1 (7.14)	2 (15.38)
	7 Consistent Players					
Position						
OL	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)
DL	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)
RB	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)
TE	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)	1 (14.29)
LB	3 (42.86)	3 (42.86)	3 (42.86)	3 (42.86)	3 (42.86)	3 (42.86)
Playing-time role						
Starter	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Rotational	3 (42.86)	3 (42.86)	3 (42.86)	3 (42.86)	3 (42.86)	3 (42.86)
Nonstarter	4 (57.14)	4 (57.14)	4 (57.14)	4 (57.14)	4 (57.14)	4 (57.14)

Abbreviations: DL, defensive lineman; LB, linebacker; OL, offensive lineman; RB, running back; TE, tight end.

Athletes were not considered if they were performing modified workouts due to the postconcussion return-to-play process.

All individuals agreed orally and with written informed consent to participate. This study was approved by the university's institutional review board (No. 1757959-5) and in accordance with the Declaration of Helsinki.

Practice Plans and GCs

We selected 6 (3 wearing traditional helmets [TRAD] and 3 with GCs affixed to traditional helmets [GC]) nearly identical practice plans that contained similar levels of hitting and times for drills. These 6 practices were chosen because they depicted common NCAA American football workouts, were not deemed scrimmages, and had only slight variations in practice plans. We vetted all preseason practice plans and carefully picked these 6 workouts after video verification to ensure they had similar workout plans. The practices were during the middle of the preseason, as at the time of this study, the athletic department intended to use GCs only during the preseason. The practices lasted approximately 2 hours, with 15 minutes of tackling drills, 25 minutes of individual position drills (which included a tackling circuit), 60 minutes of team drills using THUD (initiation of contact at full speed with no predetermined winner but no takedown to the ground) tackling, and 20 minutes of team tempo play TAG (tackling to the ground).

The TRAD practices occurred within 24 hours of one another, whereas the GC practices occurred with 5 days between sessions. The last TRAD practice was 2 days before the first GC practice session; therefore, all 6 included workouts occurred within a single athletic season. The days between GC practices varied due to the sports season moving from the acclimation period and preseason to the regular season.[13] During the regular season, full-contact TAG is limited to 1 full-contact day each week per NCAA recommendations.[13] All participants in the GC portion of the study had GCs that were fitted by the equipment staff and verified as in working condition before each session.

Instrumented Mouthguards

Before the season, each participant underwent dental scanning and was provided with a custom mouthguard created by Prevent Biometrics. Based on preliminary data using the industry standards for head impact verification, the Prevent mouthguard's custom head-impact filtering algorithm has a sensitivity of 0.75 for false-negative detection and a specificity of 0.95 for false-positive performance.[14] When a participant incurred a blow $\geq 5g$ PLA, the sensor collected data for 16 pretrigger and 144 posttrigger samples. Each participant was instructed to always wear the iMG and to refrain from placing it in areas that might cause breakage. In addition, all reported true-positive head impacts were video verified using 3 camera (model 4k/HD AG-UX180 Handheld Camcorder; Panasonic) angles (both end zones and the 50-yard line) on a full-size practice field. One person, with NCAA Division I film review experience, video verified all the true-positive head impacts. Of the 828 recorded impacts, 19 could not be video verified and

Table 2. Peak Linear Acceleration (PLA), Peak Angular Acceleration (PAA), and Total Impacts for the Entire Sample and the 7 Consistent Players

Variable	Practice No., Mean ± SD: Traditional Helmets 1	2	3	Guardian Caps 4	5	6	*P* Value
	Full Sample (n = 25)						
PLA, *g*	16.3 ± 2.1	16.5 ± 1.9	16.4 ± 2.7	16.2 ± 2.6	18.2 ± 4.3	18.3 ± 3.0	.17
PAA, rad/s^2	970.8 ± 191.0	1020.4 ± 236.9	956.86 ± 264.9	1064.4 ± 297.2	1118.0 ± 295.3	1017.1 ± 244.5	.50
Total impacts	8.8 ± 4.1	9.8 ± 5.5	9.2 ± 5.4	10.3 ± 6.1	9.4 ± 6.0	9.5 ± 5.3	.98
	7 Consistent Players						
PLA, *g*	15.7 ± 1.2	16.8 ± 2.1	16.2 ± 2.4	15.8 ± 2.7	17.2 ± 4.5	18.6 ± 3.1	.67
PAA, rad/s^2	927.6 ± 195.5	1000.3 ± 203.6	925.6 ± 155.2	955.8 ± 139.4	955.5 ± 159.8	1202.2 ± 370.0	.80
Total impacts	9.7 ± 3.0	9.7 ± 6.7	9.4 ± 5.2	10.9 ± 6.5	7.7 ± 5.6	9.3 ± 6.2	.82

were removed from the study. The PLA, PAA, and total number of impacts were analyzed across the 6 practice sessions. Each impact was considered an individual event and ensemble averaged.

Table 3. Significance (*P* Values) for Pairwise Comparisons of Peak Linear Acceleration, Peak Angular Acceleration, and Total Impacts for the Entire Sample and the 7 Consistent Players

Sample	TRAD 1	TRAD 2	GC 1	GC 2
	Peak Linear Acceleration, rad/s^2			
Full sample				
TRAD 2	.88			
TRAD 3	.17	.20		
GC 2			.10	
GC 3			.94	.16
7 Consistent players				
TRAD 2	.39			
TRAD 3	.64	.58		
GC 2			.33	
GC 3			.07	.40
	Peak Angular Acceleration, *g*			
Full sample				
TRAD 2	.56			
TRAD 3	.29	.69		
GC 2			.38	
GC 3			.22	.84
7 Consistent players				
TRAD 2	.60			
TRAD 3	.99	.46		
GC 2			.93	
GC 3			.15	.10
	Total Impacts			
Full sample				
TRAD 2	.49			
TRAD 3	.24	.80		
GC 2			.70	
GC 3			.83	.85
7 Consistent players				
TRAD 2	1.00			
TRAD 3	.90	.88		
GC 2			.34	
GC 3			.62	.31

Abbreviations: GC, 3 practice sessions with the Guardian Cap; TRAD, 3 practice sessions with traditional helmets.

Statistical Analysis

We examined all data for influential skewness and kurtosis. The head kinematics data were normally distributed, and an initial independent-samples *t* test showed no statistical difference between the TRAD and GC practices in all head kinematic data (Table 2). Independent-samples *t* tests were used for the 83 individual observations, as a varying number of the 25 participants engaged in each workout. Thus, we collapsed the TRAD and GC sessions separately and performed 1-way analyses of variance (ANOVAs) for PLA, PAA, and total impacts. One-way ANOVAs were used for the same reasoning as the independent-samples *t* tests: repeated measures are not warranted when sample sizes vary at each time point. In addition, the 7 players who had complete data sets were independently analyzed using repeated-measures ANOVAs across all 6 sessions for PLA, PAA, and total impacts. Follow-up paired-samples *t* tests were conducted in the event of a significant time effect for the entire sample (Table 3), as well as independent-samples *t* tests for the 7 consistent players (Table 3). The α level was set at .05 a priori.

RESULTS

TRAD and GC Values for PLA, PAA, and Total Impacts

The mean values for the average PLA, PAA, and total impacts for the collapsed TRAD and GC workouts using data from both the entire sample and only the 7 consistent players can be found in Table 4. The mean values for the average PLA,

Table 4. Peak Linear Acceleration (PLA), Peak Angular Acceleration (PAA), and Total Impacts for the Entire Sample and the 7 Consistent Players

Variable	3 Practice Sessions, Collapsed Mean ± SD: Traditional Helmets	Guardian Caps	*P* Value	Cohen *d* Value
Full sample (n = 25)				
PLA, *g*	16.3 ± 1.99	17.2 ± 3.27	.20	0.33
PAA, rad/s^2	992.1 ± 209.17	1029.4 ± 261.01	.51	0.16
Total impacts	9.2 ± 4.69	9.7 ± 5.65	.72	0.09
7 Consistent players				
PLA, *g*	16.2 ± 1.18	17.2 ± 2.79	.32	0.47
PAA, rad/s^2	951.2 ± 95.40	1038.0 ± 166.81	.29	0.64
Total impacts	9.6 ± 4.15	9.7 ± 5.04	.88	0.02

PAA, and total impacts for each individual workout are available in Table 2.

One-Way ANOVA PLA, PAA, and Total Impacts Across the Entire Sample

A 1-way between-participants ANOVA revealed no difference between the collapsed mean TRAD and GC PLA ($F_{1,83} = 1.67$, $P = .20$), PAA ($F_{1,83} = 0.44$, $P = .51$), or total impacts ($F_{1,83} = 0.13$, $P = .72$). These data suggest that the head kinematics for all players did not differ before and after GC implementation.

One-Way Repeated-Measures ANOVA Across the 7 Consistent Players

A 1-way within-participants repeated-measures ANOVA yielded no differences between the collapsed mean PLA ($F_{1,6} = 1.16$, $P = .32$), PAA ($F_{1,6} = 1.36$, $P = .29$), or total impacts ($F_{1,6} = 0.03$, $P = .88$) for the TRAD and GC conditions (Table 4). These data indicate that, in players who participated in all 6 practice sessions, the GC did not alter the head kinematics data.

DISCUSSION

To address the growing concern around RHIs and brain injury risk in sport, the purpose of our study was to evaluate the effect of GCs on head kinematics during similar on-field preseason practices in American football using iMGs. To our knowledge, this is the most diverse on-field measurement of iMGs using GCs, with an analysis of 809 unique video-verified head impacts across various players, positions, and playing time roles. We were able to obtain multiple practices' worth of data from the same players throughout a single season, which other researchers have not been able to accomplish. The major outcome was that the GCs did not reduce or attenuate the PLA or PAA or alter the total number of head impacts during the 6 closely matched practice sessions. In addition, no changes in any variables were noted after implementation of the GCs when the same 7 athletes were compared across the 6 practice sessions. Despite reporting by media outlets that GCs greatly reduced the incidence of concussion, those findings were not peer reviewed and have not been backed by publicly available data, whereas our results suggested they did not affect overall head kinematic data on the field.[9,15] Although no direct link exists between head kinematic data and concussions, the total amount of head impact exposure (ie, frequency and magnitude) is generally higher in the days leading up to a concussion diagnosis.[16,17] Our outcomes did not indicate that the GCs reduced overall head impact exposure; however, we did not track concussions.

These results support prior laboratory research demonstrating that GCs did not reduce head kinematic data during use.[10,18] The majority of the published investigations on GCs reflects laboratory research, which has consisted of dropping the GCs from various heights and measuring the linear acceleration the helmet experienced when hitting the ground. Laboratory testing is highly recommended for preliminary investigations on safety concerns when implementing new technology in sport, yet it lacks ecological validity. The most effective line of testing is to apply the technology in a real-world setting, which is what we aimed to do by using GCs during closely matched practices. When we directly compared our data with previously published laboratory examinations of GCs, the PLA and PAA were similar to the results of existing research.[18]

In addition to supporting prior laboratory research on GC efficacy, our findings align with the 2022 National Athletic Trainers' Association position statement regarding strategies for reducing headfirst contact behavior in American football.[19] The statement proposed that companies producing helmet add-ons often amplified the reduction in head injuries, which may have caused an increase in high-contact play due to the perception of reduced risk.[19] The statement also indicated that the efficacy of helmet add-ons has not been established; therefore, no evidence supports widespread use.[19] We observed no differences in PLA, PAA, or total impacts with GC implementation, which suggests this particular cohort may not have engaged in riskier play due to the perception of decreased injury risk from GCs. If future researchers note a reduction in PLA or PAA with no change in total impacts when players are wearing GCs, that could be considered evidence that players engaged in riskier behavior due to perceptual changes. Nonetheless, our examination offered no evidence to imply any behavioral effects. That said, the nonsignificant results in this study provided on-field evidence that GCs may not be effective in mitigating head impact kinematics in American football.

To our knowledge, only a single study used on-field data to validate the use of GCs.[11] Cecchi et al used iMG analyzed data from 5 Division I linebackers collected from 13 practices using traditional helmets without GCs in 2019 and 14 practices using GCs attached to traditional helmets in 2021.[11] The 5 players in the earlier study were not consistent throughout the 2 recorded seasons. Though our research involved significant methodologic differences, as we analyzed data from a larger sample set over the course of a single season, the examination by Cecchi et al is currently the only published work available for comparison.[11] We found no differences in PAA, PLA, or total impacts, as did Cecchi et al.[11] They also reported no differences in diffuse axonal multi-axis general evaluation or head acceleration response metric; however, we did not evaluate these variables. The combined results from Cecchi et al and the present study strongly suggest that GCs were not effective in reducing the amount and the magnitude of head kinematics experienced by collegiate American football players.[11]

Research Implications

Our outcomes suggested that GCs were ineffective in attenuating the linear and rotational head kinematics experienced by collegiate American football players, although they might be effective when applied to other helmets.

Limitations

Our investigation had limitations related to the method of data collection, as it might have been more beneficial to obtain data during games as opposed to practices; still, GCs are not allowed during games. Previous researchers have shown that the game concussion rate for collegiate American football players was 3.74 per 1000 athlete-exposures versus the practice concussion rate of 0.53 per 1000 athlete-exposures.[20] Comparing GC and non-GC data from American football games would allow us to see the effectiveness of GCs in a game setting. An additional limitation of this study was that we did not consider behavioral differences while the players were wearing GCs. It is possible that the players felt more or less protected with the additional padding, which changed the way they played. Our data did not reveal a change in total impacts from TRAD to GC; however, we cannot firmly conclude that no behavioral differences in the players' practice style occurred while wearing the GCs. Additionally, not all players wore the same helmet underneath the GC, nor did we analyze whether a certain helmet paired better with the GC to reduce the head kinematics experienced by American football players. Furthermore, GCs are affixed mainly by Velcro straps and tend to slide off the players' helmets during high-contact drills or scrimmages. Though the workouts included in this study were video verified and data would have been excluded had the GC come off completely, we cannot guarantee that the GC was not dislodged during some of the impacts. Our work would have also benefited from a second video reviewer simply to ensure high levels of quality control when reviewing the practice film for impacts. Lastly, no concussion rates were tracked during this study, as the performance period was too short, and such data may be more suited to a larger multiteam study to achieve sufficient power.

CONCLUSIONS

Consistent with the limited literature on GCs, we found no reduction in PAA, PLA, or total impacts when the GCs were affixed to traditional helmets in collegiate American football players. As significant head injuries are prominent in American football and other contact sports and with only a small literature base examining the effects of RHIs, continued research into improvements to contact sports equipment is needed.

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Address correspondence to Nicholas G. Murray, PhD, Neuromechanics Laboratory, Department of Kinesiology, School of Public Health, University of Nevada, Reno, 1664 N Virginia Street, m/s 0274, Reno, NV 89557. Address email to nicholasmurray@unr.edu.