

The Ability of an Aftermarket Helmet Add-On Device to Reduce Impact-Force Accelerations During Drop Tests

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Context: The Guardian Cap provides a soft covering intended to mitigate energy transfer to the head during football contact. Yet how well it attenuates impacts remains unknown.

Objective: To evaluate the changes in the Gadd Severity Index (GSI) and linear acceleration during drop tests on helmeted headforms with or without Guardian Caps.

Design: Crossover study.

Setting: Laboratory.

Patients or Other Participants: Nine new football helmets sent directly from the manufacturer.

Intervention(s): We dropped the helmets at 3 velocities on 6 helmet locations (front, side, right front boss, top, rear right boss, and rear) as prescribed by the National Operating Committee on Standards for Athletic Equipment. Helmets were tested with facemasks in place but no Guardian Cap and then retested with the facemasks in place and the Guardian Cap affixed.

Main Outcome Measure(s): The GSI scores and linear accelerations measured in g forces.

Results: For the GSI, we found a significant interaction among drop location, Guardian Cap presence, and helmet brand at the high velocity ($F_{10,50} = 3.01$, $P = .005$) but not at the low ($F_{3,23,16.15} = 0.84$, $P = .50$) or medium ($F_{10,50} = 1.29$, $P = .26$) velocities. Similarly for linear accelerations, we found a significant interaction among drop location, Guardian Cap presence, and helmet brand at the high velocity ($F_{10,50} = 3.01$, $P = .002$, $\omega^2 = 0.05$) but not at the low ($F_{10,50} = 0.49$, $P = .89$, $\omega^2 < 0.01$, $1-\beta = 0.16$) or medium ($F_{5,20,26.01} = 2.43$, $P = .06$, $\omega^2 < 0.01$, $1-\beta = 0.68$) velocities.

Conclusions: The Guardian Cap failed to significantly improve the helmets' ability to mitigate impact forces at most locations. Limited evidence indicates how a reduction in GSI would provide clinically relevant benefits beyond reducing the risk of skull fracture or a similar catastrophic event.

Key Words: Guardian Cap, peak acceleration, Gadd Severity Index, traumatic brain injuries

Key Points

- For both Gadd Severity Index and peak linear acceleration, the Guardian Cap did not alter impact severity on a helmet drop-testing battery.
- Additional padding applied to the helmet may not always reduce the severity of the impact on a drop test.

The acute and long-term outcomes of traumatic brain injury have become an increasingly important concern for both military personnel and civilians. Youths who participate in contact sports constitute one of the largest at-risk populations because of the large number of participants, the increased risk of head impacts, and the fact that their brains are still developing.^{1,2} The highest concussion incidence rate in high school athletes was 0.47 per 1000 exposures among football players.³ In addition, recent work has demonstrated that between 70% and 95% of high school football athletes exhibited substantial neurophysiological changes without easily identifiable symptoms.⁴⁻¹⁰ These changes depend primarily on the number and rate of head impacts as well as their magnitude and location. The effects persist well into the offseason and may not resolve by the beginning of the subsequent season.¹¹ Whether the accrual of such changes increases the likelihood of concussion or other forms of long-term damage is unknown, but it is

clear that decreasing the number and magnitude of head impacts are important goals.

Due to current concern over the long-term consequences of head impacts, technologies have been developed with the aim of reducing their magnitude. One such technology is the Guardian Cap (Guardian, Peachtree Corners, GA), which is a soft covering that can be worn over a helmet and is intended to mitigate blows to the head, reducing head accelerations caused by impacts. However, the degree to which the Guardian Cap reduces impact severity has not been measured. Such evidence is valuable to clinicians, coaches, and equipment staff attempting to evaluate safety equipment options. To evaluate their effectiveness, we tested a set of Guardian Caps using a method based on the standard provided by the National Operating Committee on Standards for Athletic Equipment (NOCSAE). We hypothesized that the Guardian Caps would reduce Gadd Severity Index (GSI) scores and peak accelerations, the former being a common head injury criterion.

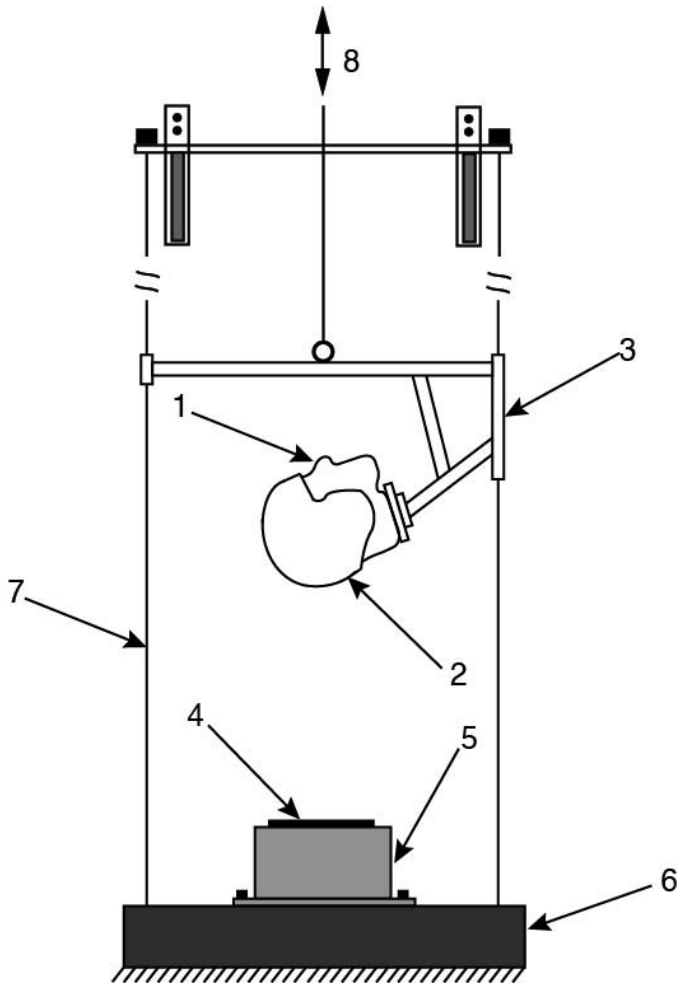


Figure 1. The impact rig consists of (1) a National Operating Committee on Standards for Athletic Equipment–certified headform with (2) the test helmet fitted and secured according to standard protocols. The headform and helmet are attached to (3) the drop carriage, which is a rigid frame that slides smoothly over (7) two 1/8-in (0.3175-cm) piano wires. The headform-helmet system strikes a (4) 1/2-in (1.27-cm) Modular Elastomer Programmer test pad (Cadex Electronics Inc, Richmond, BC, Canada) secured to (5) an anvil and (6) an anvil base plate for stability. (8) A motor moves the drop carriage up to the correct height so that it can achieve the preset impact velocity after the drop.

METHODS

The NOCSAE maintains a standard for helmet certification, and for this study, we adhered as closely as possible to this standard. The test rig has been described previously.¹² Briefly, it consists of a molded polyurethane impact surface, anvil, adjustable headform (size medium: circumference = 7¼ in [18.415 cm]), drop carriage, lifting cable, hoist motor, and guide wires (Figure 1). A triaxial accelerometer (PCB Piezotronics, Inc, Depew, NY) was placed in the headform at the point of the center of gravity to measure the acceleration of the head. Impact velocity was measured using a time/velocity gate (Cadex Electronics Inc, Richmond, BC, Canada). The acceleration and velocity data were then acquired by a National Instruments Corp (Austin, TX) data-acquisition board sampling at 10 kHz and controlled by a LabVIEW (National Instruments Corp) program. An additional MATLAB (The MathWorks, Inc, Natick, MA) program performed basic data analysis,

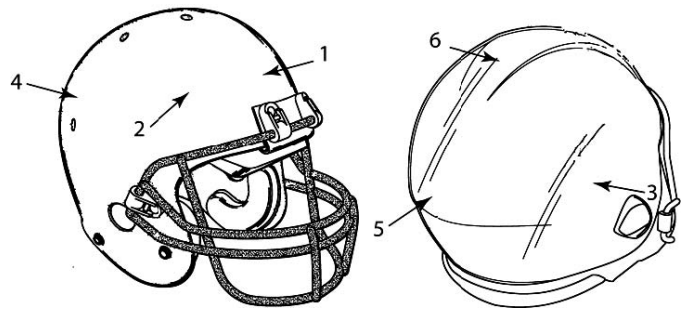


Figure 2. Front and rear views of typical helmets adapted from US Patents 20120297525 and 20130180034. Each helmet was tested in 6 locations: (1) front, (2) front boss, (3) side, (4) rear boss, (5) rear, and (6) top, as indicated.

such as computing the GSI and verifying that the drop was compliant with test requirements, and provided a user interface for data collection.

Calibration of the accelerometer was conducted using a certified accelerometer calibration device (PCB Piezotronics, Inc). This procedure ensured that true accelerations and GSI were determined for the impacts. However, this contrasts with the NOCSAE calibration procedure, in which accelerometer sensitivities are adjusted so that the headform generates a specified GSI. The NOCSAE procedure creates consistency among laboratories, but it also biases test-rig–dependent differences in actual impact accelerations. Because our objective was to understand actual differences in impact severity between helmets with and without the Guardian Cap, use of the certified calibration device was appropriate.

When evaluating protective headgear,^{13–15} the NOCSAE standards state that, for each helmet to meet the certification requirement, it must be dropped (without the facemask affixed) at 6 drop locations (front, side, right front boss, right rear boss, rear, and top) and 1 random location (Figure 2). However, the Guardian Caps were designed to attach to the facemask, so we attached the facemask to the helmet for the purposes of this study. Testing was conducted at ambient temperatures (defined as 72°F ± 5°F), per the standard; high-temperature tests were not attempted. Another deviation from the standard was the elimination of the random drop-test location. We dropped the helmets at impact velocities of 3.46 m/s (low), 4.89 m/s (medium), and 5.47 m/s (high) at each impact location.^{13–16}

In this crossover study, each of the 3 helmets was tested with and without the Guardian Caps at each of the 6 drop locations. We based our sample size on power analyses using 2 previously published studies^{17,18} with similar data, which indicated that 3 helmets per group would be sensitive to differences in impact attenuation ($\alpha = .05$ and $1 - \beta = 0.80$). The experimental design for the Riddell Speed helmets (Riddell Sports, Elyria, OH) is seen in Figure 3. This same protocol was implemented for the Xenith X2E helmets and the Xenith Epic helmets (Xenith, Detroit, MI).

Data-Collection Procedures

Before starting the drops for a given helmet or location, we conducted a system check to ensure that the test rig had not loosened or drifted from a stable configuration. Consistent with NOCSAE requirements, this check ensured

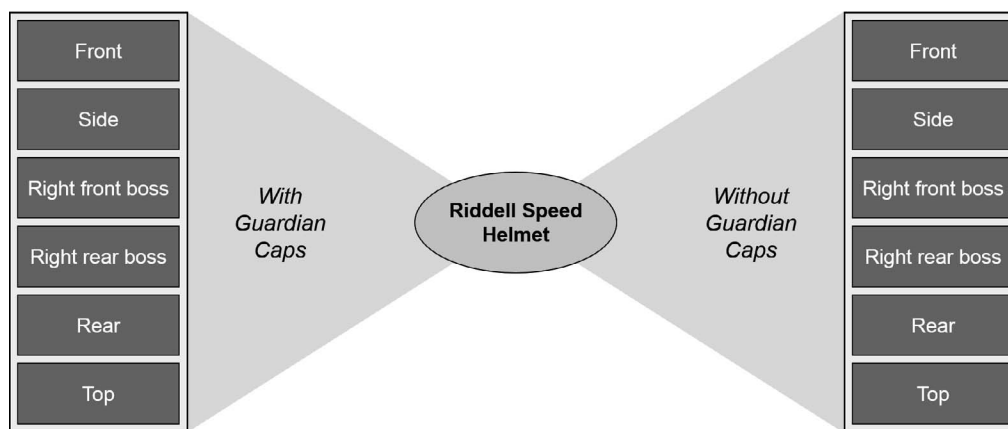


Figure 3. In this crossover study, each helmet underwent testing with and without the Guardian Cap at each of the 6 drop locations. The experimental design for the Riddell Speed helmet is shown.

that peak acceleration and the GSI had not changed by more than 7% for a standard drop. After the system check, a helmet was fit to the headform according to the manufacturer's specifications. We purchased 3 new Riddell Speed football helmets, 3 new Xenith X2E football helmets, and 3 new Xenith Epic football helmets for the present study, and the manufacturer provided 9 new Guardian Caps. All helmets were size large. The third Xenith X2E helmet was rendered unsuitable during the testing process, and thus, these data are not included in this dataset. All helmets tested were fitted to the medium NOCSAE headform (7¼-in [18.415-cm] circumference). The helmet was oriented 1 in [2.54 cm] from the top of the eyebrows, and the 4-point chin strap was applied for improved fit. Helmet fit was achieved when the helmet did not rotate, shift, or slide on the headform and no gap was present between the front helmet liner and the forehead. The time between drops was 75 ± 15 seconds.

Statistical Analysis

We used SPSS Statistics (version 21; IBM Corp, Armonk, NY) to run a repeated-measures analysis of variance to determine the effect of Guardian Cap and helmet brand on GSI scores at each of the 3 prescribed velocities. We used drop location as the repeated variable and set the α level to .05 a priori. We used the Greenhouse-Geisser correction when the Mauchly test of sphericity was significant, indicating that the data were heteroskedastic for different impact locations. In addition, we examined the effect of the Guardian Cap on peak acceleration at all 3 velocities using the same statistical approach.

RESULTS

Gadd Severity Index Scores

All 18 trials passed the NOCSAE GSI threshold at all 3 velocities for each of the 6 drop locations, regardless of whether a Guardian Cap was applied or not (Figure 4). We found a significant interaction among drop location, Guardian Cap presence, and helmet brand at the high velocity ($F_{10,50} = 3.01, P = .005, \omega^2 = 0.03$) but not at the low ($F_{3,23,16.15} = 0.84, P = .50, \omega^2 = 0.01, 1-\beta = 0.20$) or

medium ($F_{10,50} = 1.29, P = .26, \omega^2 < 0.001, 1-\beta = 0.40$) velocities. When analyzing the 3-way interaction at the high velocity, we uncovered a significant 2-way interaction for helmet make and location ($F_{10,50} = 28.99, P < .001, \omega^2 = 0.32$). However, the 2-way interactions for location and Guardian Cap presence ($F_{1,50} = 2.31, P = .16, \omega^2 < 0.01, 1-\beta = 0.28$) and helmet brand and Guardian Cap presence ($F_{2,10} = 0.39, P = .69, \omega^2 < 0.01, 1-\beta = 0.10$) were not significant. Because the 2-way interaction between helmet brand and Guardian Cap presence was not significant, further pairwise tests were not conducted.

Peak Accelerations

Similar results were obtained for the peak accelerations (Figure 5). We found a significant interaction among drop location, Guardian Cap presence, and helmet brand at the high velocity ($F_{10,50} = 3.01, P = .002, \omega^2 = 0.05$) but not at the low ($F_{10,50} = 0.49, P = .89, \omega^2 < 0.01, 1-\beta = 0.16$) or medium ($F_{5,20,26.01} = 2.43, P = .06, \omega^2 < 0.01, 1-\beta = 0.68$) velocities. When analyzing the 3-way interaction at the high velocity, we uncovered significant 2-way interactions for helmet make and location ($F_{10,50} = 22.63, P < .001, \omega^2 = 0.25$) and location and Guardian Cap presence ($F_{5,50} = 2.52, P = .04, \omega^2 = 0.009$). Given our investigative aim, we further assessed the 2-way interaction for Guardian Cap and location. The presence of the Guardian Cap decreased peak acceleration at both the right rear boss ($99.98 \pm 19.66, P = .32$) and rear ($111.28 \pm 11.72, P = .10$) locations, when compared with no Cap (right rear boss: 112.55 ± 19.66 , rear: 123.35 ± 13.53). No differences occurred at any other locations for the presence of the Guardian Cap. However, the 2-way interaction for helmet brand and Guardian Cap presence was not significant ($F_{2,10} = 1.23, P = .33, \omega^2 < 0.001, 1-\beta = 0.21$). Because the 2-way interaction between helmet brand and Guardian Cap presence was not significant, further pairwise tests by helmet brand were not conducted.

DISCUSSION

The goal of our study was to determine the effect of an aftermarket device designed to reduce impact magnitude by means of a testing protocol similar to that used by the NOCSAE to certify helmets. At various combinations of

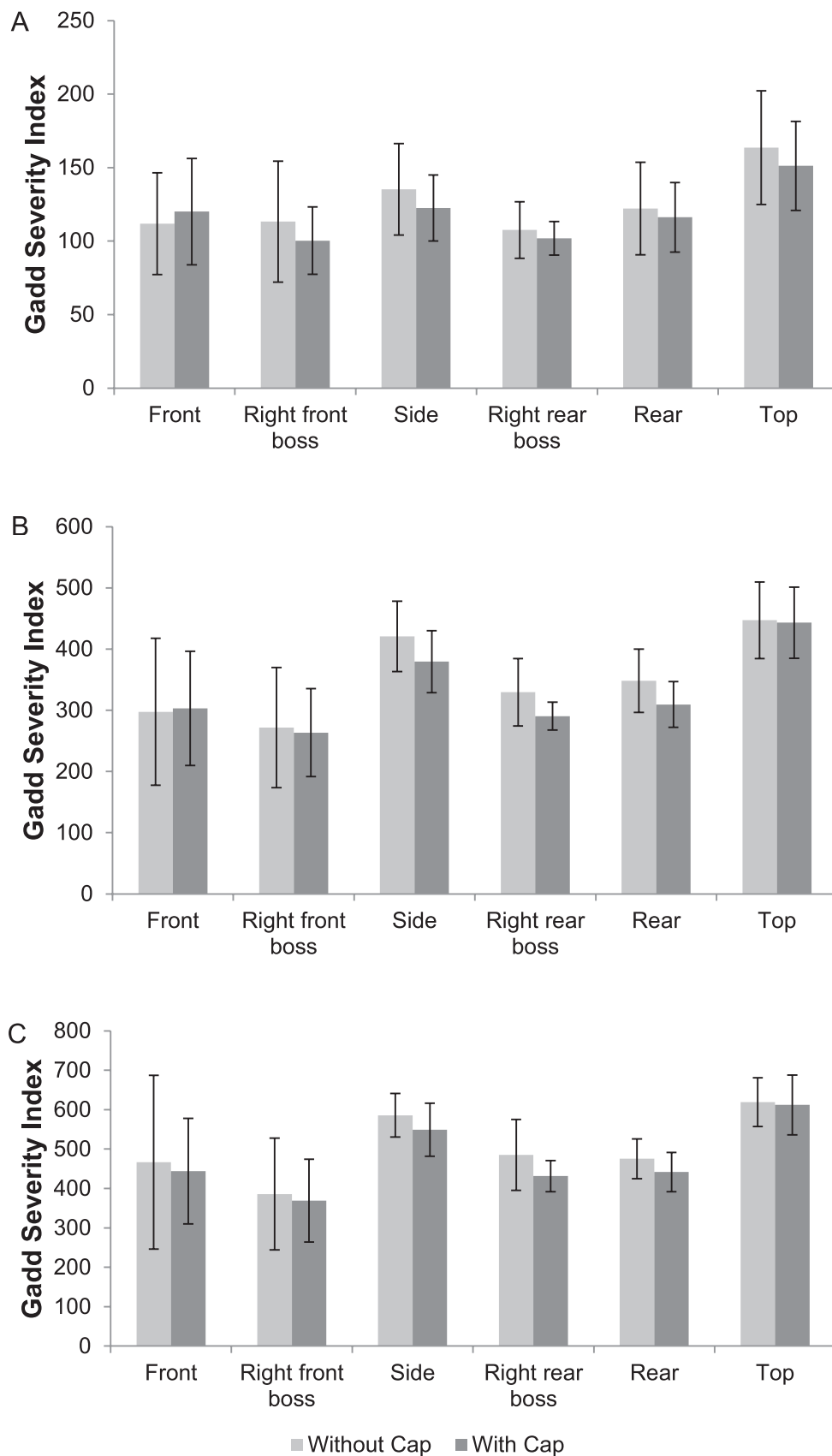


Figure 4. Gadd Severity Index scores (mean \pm SD) measured for helmets with or without Guardian Caps at high velocity (5.47 m/s). A, Riddell Speed (Riddell Sports, Elyria, OH). B, Xenith X2E (Xenith, Detroit, MI). C, Xenith Epic.

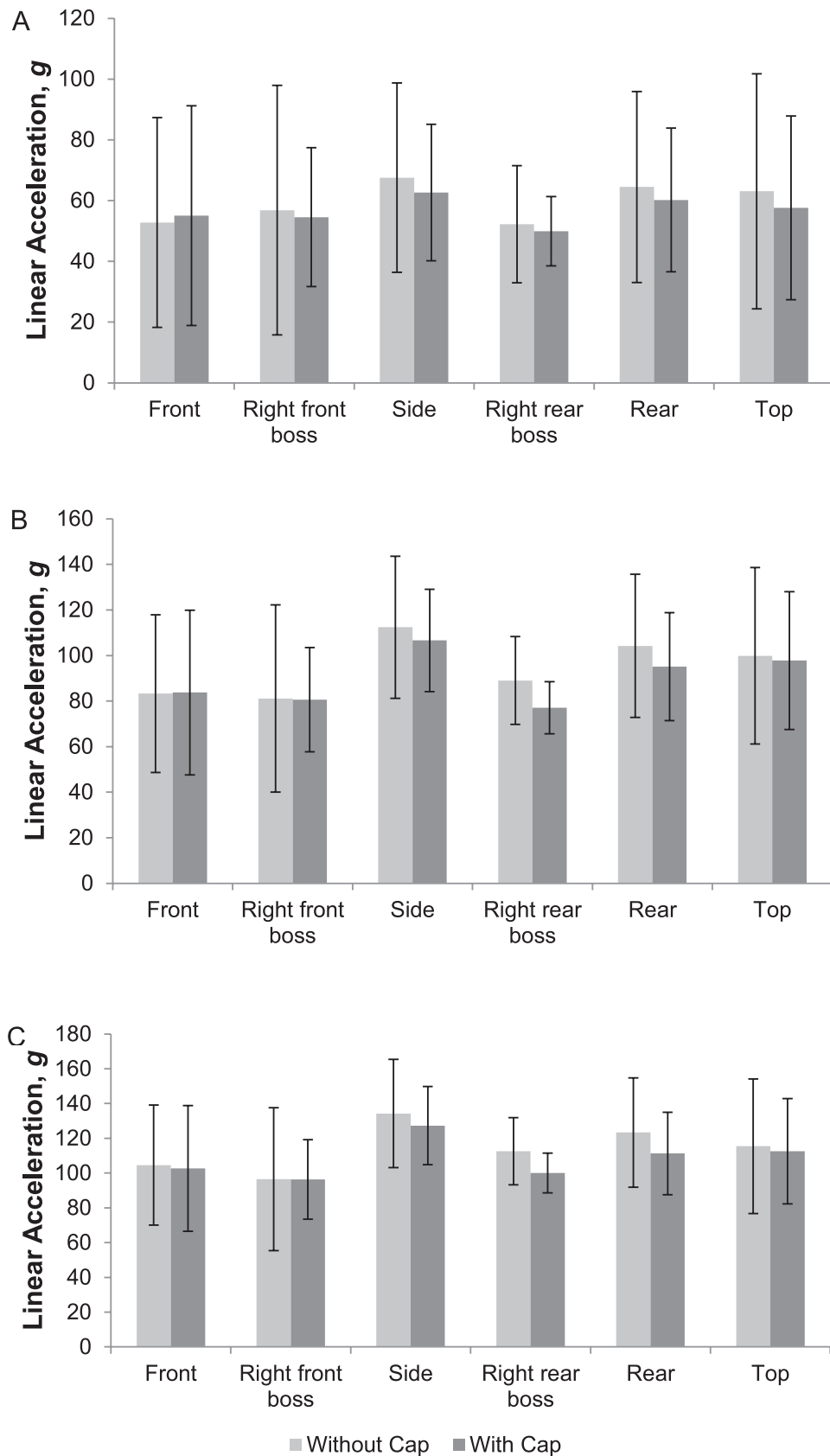


Figure 5. Peak linear acceleration (mean \pm SD) measured for helmets with and without Guardian Caps at high velocity (5.47 m/s). A, Riddell Speed (Riddell Sports, Elyria, OH). B, Xenith X2E (Xenith, Detroit, MI). C, Xenith Epic.

drop location and impact speed, peak acceleration decreased at the rear boss and rear positions. However, these positions are the least common sites for head impacts during football participation. No differences were present for GSI based on Guardian Cap condition.

From a mechanical standpoint, it is reasonable to hypothesize that the Guardian Cap padding is sufficiently thin and compliant that it “bottoms out” (ie, the foam is compacted) during impact and does not meaningfully change the overall compliance of the helmet system.¹⁹ Because the padding is on the outside of the helmet, it also does not benefit from the force-spreading effect of the hard helmet shell.^{20–22} Indeed, with the waffle pattern, only a handful of padding pods are involved in any given impact, further limiting the opportunity for energy dissipation by the additional padding of the Cap.

The modified NOCSAE protocol represents 1 type of analysis that should be used to determine the efficacy of an aftermarket device such as the Guardian Cap in reducing head-impact severity. It should be noted, however, that the NOCSAE standard was developed in an effort to eliminate skull fractures and not the kind of neurophysiological change that has been shown to occur from concussive and subconcussive blows.²³ Consequently, it is not currently possible to determine if any reduction in the GSI is related to a reduction in either the concussion risk or the risk of long-term neuropsychological deficits. However, at this point, we are unaware of any studies supporting the use of third-party aftermarket helmet add-ons to reduce head injury.

For the purposes of this study, we followed the NOCSAE testing protocol as closely as possible. Although we tested only 9 Guardian Caps on 9 helmets, the statistical soundness of these findings is reinforced by the very small effect sizes. Based on the *P* values and the effect sizes,^{24,25} we are confident that the Guardian Caps did not decrease GSI scores or peak accelerations and the differences noted are likely due to chance. We suggest studying the effect of third-party aftermarket helmet add-ons using a wider variety of helmets. It would also be interesting to see how the performance of aftermarket helmet add-ons changes after the helmet receives repetitive impacts.

CONCLUSIONS

Commonly used football helmets were drop tested with and without the Guardian Cap aftermarket device. Neither the GSI nor the peak acceleration was statistically altered by the presence of the device in all but 2 situations. Although neither metric strictly predicts concussive risk, we could not conclude that the Guardian Cap provided measureable impact mitigation.

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