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Research Article

Softer Foam in Bicycle Helmets Reduces the Impact Force in a Simulation Model

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Abstract

Objective: This study compared the linear acceleration generated from an impact to a manikin's head wearing an off-the -shelf “standard” bicycle helmet (stdBH) compared to a modified bicycle helmet (modBH) (original foam replaced with softer polyolefin foam).

Methods: Pairs of 5 different bicycle helmets from a wide price range ($20-$90) were tested (standard versus modified). The head impact was simulated by striking the test bicycle helmet placed onto the head of a Century BOB boxing manikin, with a conventional football helmet (4.6 kg additional weight added) swung from a 1.2 meter rope and released from an angle of 45° serially for multiple data points as in Figure 2. The manikin's bicycle helmet was struck by the football helmet in the frontal, left parietal, and occipital locations for 12 trials each. Each of three accelerometers located at the manikin’s forehead, apex of the head, and right ear collected data on linear acceleration in the X, Y, and Z planes.

Results: Mean linear acceleration in G's (9.8 m/sec/sec) was obtained from the three accelerometer locations on the manikin's head for each striking position. The mean linear accelerations across the 5 different helmet pairs are summarized in the graphs (Figure 3). For each of the three striking locations, there were statistically lower striking forces sustained with the modified softer foam bicycle helmet (modBH) compared to the standard bicycle helmet (stdBH). The greatest reductions were observed in the apical accelerometers when the manikin was struck from the occipital and parietal locations.

Conclusion: These results suggest that softer foams in bicycle helmets may reduce injury from bicycle accidents. Further research on this topic can lead to the development of safer and more effective bicycle helmets.

Keywords: *Bicycling; Bicycle helmet; Bicycle Accidents; Head Trauma; Injury Prevention*

Introduction

Bicycling accidents account for 3.5% of unintentional injury in children.[1] It is estimated that 66 per 100,000 U.S. children use emergency department services for bicycle-related injuries each year.[2] Additionally, bicycle-related injuries total approximately $200 million in related inpatient hospital costs.[2] Enforcement, modeling, and legislation, as well as community- and school-based interventions, have demonstrated increased helmet use, resulting in fewer head injuries and decreased bicycle-related mortality.[3] While the benefits of advocating helmet use are clear, there could be further safety improvements in helmet design.

Generally, there are two categories of helmet foam: 1) Stiff and crushable foams intended for a single hard impact, 2) Softer foams meant for multiple softer impacts.[4] In 1957, expanded polystyrene (EPS) was first used in automobile racing helmets.[4] In addition to being stiff and crushable, this foam was chosen because it was inexpensive, lightweight, and relatively easy to manufacture.[4] Currently, most bicycle helmets are made of EPS foam.[4] However, helmets designed for sports with a high risk of head injury, such as football, hockey, and skateboarding, typically use softer foams. In just feeling the foam, bicycle helmet foam feels hard and rigid, while the foam used in other helmets feels much softer.

Adding layers of polyolefin foam to the exterior surface of a football helmet demonstrated reduced impact forces.[5] Our hypothesis is that bicycle helmets using a softer polyolefin foam will reduce the force of impact better than bicycle helmets using the more rigid EPS foam which could reduce the injury potential when using commercial, mainstream bicycle helmets. The purpose of this study is to compare the G-forces generated from an impact to a manikin's head wearing an off-the-shelf "standard" bicycle helmet (stdBH) compared to a modified bicycle helmet (modBH) (original foam replaced with softer polyolefin foam).

Materials and Methods

Pairs of 5 different bicycle helmets were purchased from a wide price range: Bell (Vista Outdoor, Anoka, MN) Cruiser ($15, Walmart, Bentonvill, AR), Bell Summit Adult Bike Helmet ($25, Walmart), Bell Avenue LED ($70, Bell Helmets), Giro (Giro, Scotts Valley, CA) Agilis MIPS Bike Helmet ($100, REI, Seattle, WA), and Smith (Smith Optics, Ketchum, ID) Convoy MIPS Bike Helmet ($80, REI). Additionally, a youth baseball helmet was purchased. The pairs of helmets were used to create a stdBH group and modBH group. In the modBH group, the EPS foam was removed with an electric hot knife foam cutter. Next, sheets of polyolefin foam were folded and sewed together to match the thickness of the original EPS foam. The folded and sewn polyolefin foam was attached to the inner surface of the plastic outer shell of the bicycle helmets using Shoe GOO (Eclectic Products, Eugene, OR) as an adhesive (Figure 1).

Figure 1: *Left: Standardized bicycle helmet (EPS Foam); Right: Modified Bicycle Helmet (Polyolefin Foam).*

ADXL326 **-** 5V ready triple-axis accelerometers (Analog Devices, Inc., Norwood, MA) were attached to the forehead, apex of the head, and right ear of a Century Body Opponent Bag (BOB®) manikin (Century, LLC, Oklahoma City, OK). This head and torso manikin is a martial arts / boxing manikin that mounts onto a weighted base via a hollow plastic tube. The system is non-rigid to better mimic a martial arts / boxing strike. The test helmet was attached to the manikin's head. To keep the striking force consistent, a pendulum was created using a conventional football helmet (4.6 kg additional weight added) swung from a 1.2 meter rope and released from an angle of 45° serially for multiple data points as shown in Figure 2. Each helmet was struck twelve times in each of the 3 locations (frontal, occipital, and parietal). Maximum linear acceleration in G's (9.8 m/sec/sec) was obtained from the three accelerometer locations on the manikin's head for each striking position. To minimize manikin head strike location variance, the stdBH and modBH were changed without changing the manikin's position. The manikin's position was then changed only after all strikes for a given location were completed.

***Figure 2:** Simulation model setup showing the weighted football helmet and the manikin wearing the bicycle helmet.*

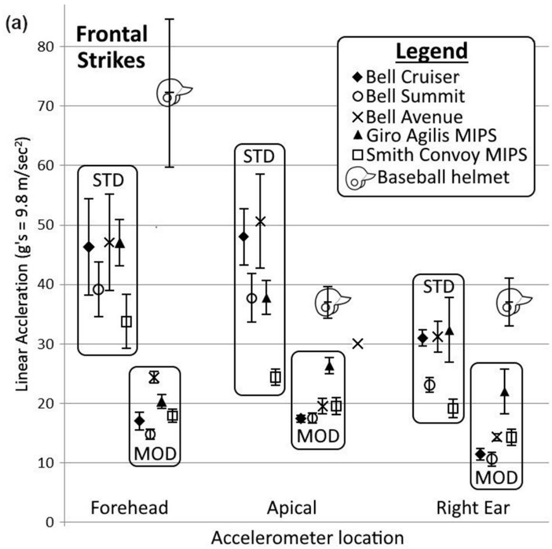
The maximum linear accelerations (in G-forces 9.8 m/sec/sec) recorded for each trial were averaged for each individual helmet. 95% confidence intervals of the mean (95%CIM) were calculated for each of the three accelerometer locations, for each of the three strike types (frontal, parietal, occipital), for each of the helmets, for comparison.

Results

The mean linear accelerations across the 5 different helmet pairs and 1 baseball helmet are summarized in Table 1 and graphed for visible comparison in Figures 3a (frontal strikes), 3b (parietal strikes), and 3c (occipital strikes). For each of the three striking locations, there were statistically lower striking G-forces sustained with the modified softer foam bicycle helmet (modBH) compared to the standard bicycle helmet (stdBH) and baseball helmet. Comparing the stdBHs and modBHs, the greatest reductions were observed in the apical accelerometers when the manikin was struck in the occipital and parietal region.

Figure 3a, 3b, and 3c: Average peak G-force acceleration categorized by strike location and helmet type. The error bars represent the 95% CIM.

Figure 3a



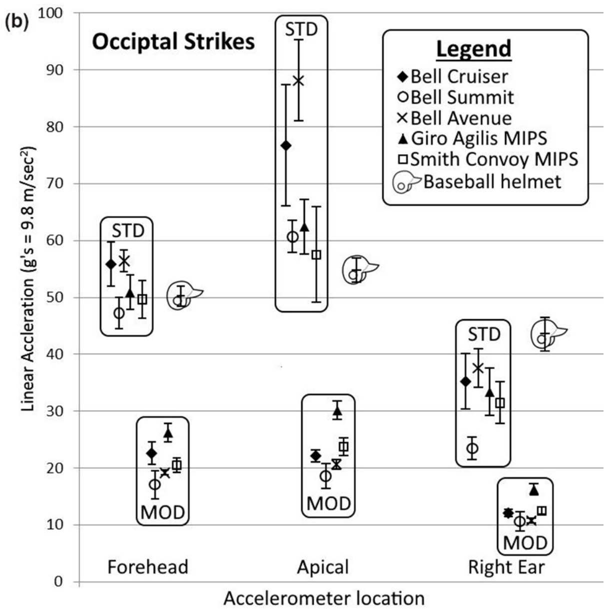


Figure 3b

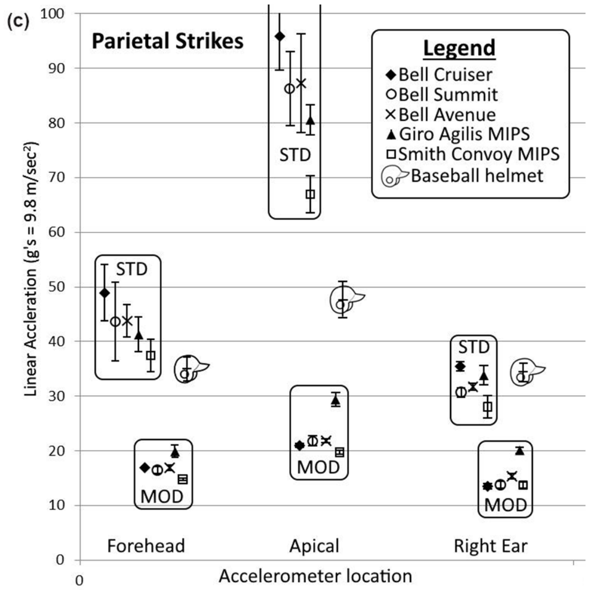


Figure 3c

Table 1: Mean linear accelerations in G's (9.8 m/sec/sec) across the 5 different helmet pairs and 1 baseball helmet.

Strike Location and Accelerometer Location	Control Hard Foam Helmet Mean Linear Acceleration Per Helmet					Modified Soft Foam Helmet Mean Linear Acceleration Per Helmet					Baseball Helmet Linear Acceleration
	1	2	3	4	5	1	2	3	4	5	
Frontal strikes											
Forehead	46.3	39.2	47.1	47.0	33.8	17.1	14.8	24.4	20.3	17.9	72.2
Apical	48.1	37.8	50.7	37.8	24.5	17.4	17.6	19.6	26.4	19.7	37.1
Right Ear	31.0	23.1	31.3	32.4	19.2	11.5	10.7	14.4	22.0	14.3	37.0
Occipital strikes											
Forehead	56.0	47.3	56.5	50.9	49.7	22.6	17.3	19.4	26.3	20.5	50.2
Apical	76.8	60.8	88.1	62.6	57.6	22.2	18.7	20.7	30.1	23.8	54.9
Right Ear	35.2	23.5	37.5	33.4	31.4	12.0	10.6	10.6	16.3	12.4	43.4
Parietal Strikes											
Forehead	48.9	43.7	43.8	41.3	37.5	16.9	16.5	16.9	19.9	14.8	35.0
Apical	95.9	86.3	87.3	80.6	66.9	21.0	21.8	21.8	29.4	19.7	47.7
Right Ear	35.5	30.7	31.7	33.8	28.0	13.5	13.8	15.3	20.1	13.7	34.3

Legend; 1 - Bell Cruiser, 2 - Bell Summit, 3 - Bell Avenue, 4 - Giro Agilis MIPS, and 5 - Smith Convoy MIPS.

Discussions

This study compared the difference in severity of a uniform strike to the head as simulated by a manikin wearing a hard-foam (off-the-shelf, EPS; stdBH) helmet versus a soft-foam helmet (modified, polyolefin; modBH). Additionally this study compared a baseball helmet, which has a soft foam lining made of ethylene-vinyl acetate, to the stdBH and modBH.

A previous study demonstrated that a mean linear acceleration of 98 G's is a key factor in the development of concussions.[4] The linear accelerations in both groups were below the threshold for a concussion injury. Future studies should increase the angle or weight of the football helmet to better mimic the force sustained in a significant traumatic brain injury (TBI). Although the rigid EPS foam of the stdBHs are designed for single use, our serial strike data did not show worsening forces sustained for the serial stdBH strikes.

In this study, we measured linear acceleration G-forces. However, rotational acceleration caused by oblique impacts should also be considered. Studies show that translational acceleration is related to pressure and rotational acceleration is dominant in shear deformations, suggesting that they contribute to different types of traumatic brain injuries.[6] Since rotational acceleration is a large contributor to concussion, diffuse axonal injury, hemorrhage, and other brain parenchymal injuries[7], a future study should include rotational acceleration measurements and a model to better mimic rotational acceleration.

Conclusion

The findings of this study highlight the importance of helmet design in improving safety outcomes for cyclists. In this manikin study, the softer foam modified bicycle helmets resulted in lesser degrees of head trauma compared to standard hard foam bicycle helmets.

Acknowledgements

None of the authors identify a conflict of interest. Abstracts of this study were presented at the Pediatric Academic Societies meeting (Denver, CO), American Academy of Pediatrics conference (Anaheim, CA), and the Biomedical Sciences & Health Disparities Symposium (University of Hawaii, John A. Burns School of Medicine).

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Conflict of Interest

The authors declare no conflict of interest.

References

1. Centers for Disease Control and Prevention. Injury prevention and control: data and statistics (WISQARS). Fatal injury data. http://www.cdc.gov/injury/wisqars/fatal.html. Accessed April 8, 2021.
2. Parkin PC, Howard AW. Advances in the prevention of children's injuries: an examination of four common outdoor activities. Curr Opin Pediatr. 2008;20(6):719–723.
3. Theurer WM, Bhavsar AK. Prevention of unintentional childhood injury. Am Fam Physician. 2013;87(7):502-509.
4. Newman, J. The biomechanics of head trauma and the development of the modern helmet. How far have we really come? In Proceedings of the IRCOBI Conference, Prague, Czech Republic, 21–23 September 2005.
5. Nakatsuka AS, Yamamoto LG. External foam layers to football helmets reduce head impact severity. Hawaii J Med Public Health. 2014;73(8):256-261.
6. Ueno K, Melvin JW. Finite element model study of head impact based on Hybrid III head acceleration: the effects of rotational and translational acceleration. J Biomech Eng. 1995;117(3):319-328. doi:10.1115/1.2794187
7. Kleiven S. Why Most Traumatic Brain Injuries are Not Caused by Linear Acceleration but Skull Fractures are. Front Bioeng Biotechnol. 2013;1:15.

8. Kroeker SG, Özkul MÇ, DeMarco AL, Bonin SJ, Siegmund GP. Density Variation in the Expanded Polystyrene Foam of Bicycle Helmets and Its Influence on Impact Performance. J Biomech Eng. 2020;142(4):041012. doi: 10.1115/1.4045709. PMID: 31833545.

9. Levy ML, Ozgur BM, Berry C, Aryan HE, Apuzzo ML. Birth and evolution of the football helmet. Neurosurgery. 2004;55(3):656-662. doi:10.1227/01.neu.0000134599.01917.aa. PMID: 15335433.

10. Broglio SP, Schnebel B, Sosnoff JJ, et al. Biomechanical properties of concussions in high school football. Med Sci Sports Exerc. 2010;42(11):2064-2071. doi:10.1249/MSS.0b013e3181dd9156

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