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The impact response of traditional and BMX-style bicycle helmets at different impact severities

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ABSTRACT

Bicycle helmets reduce the frequency and severity of severe to fatal head and brain injuries in bicycle crashes. Our goal here was to measure the impact attenuation performance of common bicycle helmets over a range of impact speeds. We performed 127 drop tests using 13 different bicycle helmet models (6 traditional style helmets and 7 BMX-style helmets) at impact speeds ranging from 1 to 10 m/s onto a flat anvil. Helmets were struck on their left front and/or right front areas, a common impact location that was at or just below the test line of most bicycle helmet standards. All but one of the 10 certified helmet models remained below the 300 g level at an impact speed of 6 m/s, whereas none of the 3 uncertified helmets met this criterion. We found that the helmets with expanded polystyrene liners performed similarly and universally well. The single certified helmet with a polyurethane liner performed below the level expected by the Consumer Product Safety Commission (CPSC) standard at our impact location and the helmet structure failed during one of two supplemental tests of this helmet above the test line. Overall, we found that increased liner thickness generally reduced peak headform acceleration, particularly at higher impact speeds.

1. Introduction

Bicycle helmets reduce the frequency and severity of head and brain injuries from bicycle crashes (Thompson et al., 1999; McIntosh et al., 2011; Persaud et al., 2012; Elvik, 2013; Bambach et al., 2013; Cripton et al., 2014). They achieve this reduction by attenuating head acceleration, increasing impact duration, and distributing the impact force over a larger area of the head than without a helmet. The effectiveness of helmets in mitigating injury has led to laws requiring bicycle helmet use in many jurisdictions. Since March 10, 1999, all bicycle helmets manufactured or imported for sale in the United States are required to meet the standard set by the U.S. Consumer Product Safety Commission (U.S. CPSC, 1998). CPSC certified helmets now dominate the North American market, although some bicycle helmets sold in North America are also (and sometimes only) certified by other agencies, such as the American Society for Testing and Materials International (ASTM, 2006a,b), the Snell Memorial Foundation (1998), the European Committee for Standardization (1997, 2007) and Standards Australia/New Zealand (AS/NZS, 1996).

Modern certified bicycle helmets, i.e., helmets <~10 years old, generally consist of an energy absorbing liner made of expanded polystyrene (EPS) or polyurethane (PU) and either a thin outer shell (traditional style) or a thick outer shell (BMX-style). Some BMX-style bicycle helmets are also certified to snow sport and/or skateboarding standards, whereas other skateboarding helmets that appear similar to BMX-style helmets are not certified to any standard, potentially confusing consumers.

Only limited impact performance data for modern bicycle helmets are available, mostly in the scientific literature (Mills and Gilchrist, 2008; Dressler et al., 2012; Mattei et al., 2012; McIntosh and Patton, 2012; Hansen et al., 2013; McIntosh et al., 2013; Cripton et al., 2014; Mizuno et al., 2014) and consumer magazines (Consumer Reports, 2007, 2009, 2012). This limited availability differs from motorcycle helmets, for which compliance test results (NHTSA, 2014) and ratings (http://www.crash.org.au/what-is-crash.html) are available online, and football helmets, which are rated with the STAR system (Rowson and Duma, 2012) also available online (http://www.sbes.vt.edu/helmet.php). Moreover, bicycle helmets are typically tested only under the conditions stipulated by the standards. For impact attenuation performance, this typically means radial impacts above a defined test line onto various anvils at specific impact speeds. While these well-defined test conditions are needed for certification, the resulting data are of lim-

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Table 1
Helmet label information.

Make and Model		Year	Size	Certifications
Traditional-style				
B1	CCM V15 Back-Trail	2009	S/M (54–58 cm)	CPSC
B2	Supercycle 073-0445-8	2009	M (54–58 cm)	CPSC, CE
B3	Giro Stylus	2007	M (55–59 cm)	CPSC
B4	Giro Prolight	2010	M (55–59 cm)	CPSC, CE EN 1078:1997/A1:2005
B5	Specialized Propero	2010	M (54–60 cm)	CPSC, Snell B90A
B6	Specialized S-Works	2010	M (54–60 cm)	CPSC, Snell B90A
BMX-style				
S1	Protec Classic 2-Stage foam	2009	M (55–56 cm)	None
S2	Protec The Classic EPS	2010	M (55–56 cm)	CPSC, AS/NZS 2063:2008, ASTM 1447, CE EN 1078
S3	Bern Watts Hard Hat	2010	M (55.5–57 cm)	None
S4	Bern Watts EPS	2009	M (55.5–57 cm)	CPSC, ASTM F 2040, CE EN 1077 – Class B, CE EN 1078
S5	Bern Brentwood Zipmold	2011	M (55.5–57 cm)	CPSC, ASTM F 2040, CE EN 1078
S6	Nutcase Street Classic Shell	2010	S/M (52–60 cm)	CPSC, AS/NZS 2063:1996, CE EN 1078, TÜV GS
S7	RED Trace	2008	M (57–59 cm)	CPSC ASTM F 2040-00, CE EN 1077

Table 2
Helmet specifications.

Make and Model	N[a]	Mass[b]	Shell		Liner		Vents
		(g)	material[c]	(mm)	material[d]	(mm)	
B1-CCM V15	15	245	PVC	0.6	EPS	22.9	13
B2-Supercycle	15	216	PVC	0.9	EPS	28.9	15
B3-Giro Stylus	10	284	PC	0.38	EPS	33.3	26
B4-Giro Prolight	8	186	PC	0.25	EPS	30.0	25
B5-Specialized Propero	10	286	PC	0.7	EPS	31.4	34
B6-Specialized S-Works	8	228	PC	0.32	EPS	32.2	30
S1-Protec 2-Stage foam	4	357	ABS	2.7	PE	24.1	11
S2-Protec EPS	10	450	ABS	2.3	EPS	22.0	11
S3-Bern Hard Hat	4	486	ABS	3.3	PP/PU[e]	21.0	11
S4-Bern EPS	11	542	ABS	3.3	EPS	18.2	11
S5-Bern Zipmold	11	346	PVC	0.9	PU	21.3	11
S6-Nutcase	10	379	ABS	3.0	EPS	16.7	11
S7-RED	11	536	ABS	2.8	EPS	21.3	10

[a] number of impact tests.
[b] mass of helmet as tested.
[c] PVC polyvinyl chloride; PC polycarbonate; ABS acrylonitrile butadiene styrene.
[d] EPS expanded polystyrene; PE polyethylene; PU polyurethane; PP polypropylene.
[e] Brock® Foam (PP beads coated with a thin layer of PU).

ited use for analyzing actual bicycle helmet impacts with varying angles, surfaces, locations and speeds. Data from real-world bicycle helmet impacts indicate that contact to a flat surface (Williams, 1991; Smith et al., 1993; Cameron et al., 1994) is common, and that 52–78 percent of the studied impacts occurred with the front/side of the helmet (McIntosh and Dowdell, 1992; Smith et al., 1993; McIntosh et al., 1995; Ching et al., 1997). Thirty-three to 63 percent of these impacts occurred at a region below the test line (Williams, 1991; Cameron et al., 1994; Ching et al., 1997). These data also indicate that impact severities above that stipulated in the certification standards do occur in some cases, albeit rarely (Williams, 1991; Cameron et al., 1994; Ching et al., 1997).

Our goal was to measure the impact attenuation performance of common North American bicycle helmets over a range of impact speeds. We performed radial impacts to the front/side of the helmet (near and sometimes below the test line) onto a flat anvil at a wide range of impact speeds (1–10 m/s). The impact speeds were chosen to cover the range we see in our crash investigations, even though we recognize that helmet impacts at the upper end of this range are rare.

2. Methods

Thirteen helmet models were tested (Tables 1 and 2, Figs. 1 and 2). All helmets had a shell, an energy absorbing liner and a comfort liner, but only 11 helmet models were certified (Table 1). The traditional bicycle helmets (numbered B1 to B6) had thin shells (<1 mm) and expanded polystyrene (EPS) liners, and one model (B6) had a dual density EPS liner. Models B1 and B2 had their shells and liners glued or taped together, whereas models B3 to B6 had their shell and liner fused, i.e., a molded-in-shell design. Models B5 and B6 had internal reinforcing advertised as a "composite matrix internal reinforcement" and "Kevlar-reinforced InnerMatrix" respectively. This reinforcing reportedly maintains tensile strength when a lower density EPS is used (Mills and Gilchrist, 2006). Liner thicknesses varied between and within each model, with the largest variability in the vent regions (traditional helmets) and near the edges (both helmets).

The BMX-style helmets (excluding S5) had thicker shells (>2 mm) and liners made of polyurethane (PU), polypropylene/polyurethane (PP/PU), polyethylene (PE) or EPS. Only helmet S5 had a molded-in-shell design; the others had their shells and liners fixed together with glue, tape or Velcro™. The BMX-style helmets had fewer vents than the traditional helmets (Table 2) and their liners generally covered more of the head. The thickness measurements reported in Table 2 represent the thickest region of the helmet within the area of impact (traditional helmets) or the thickness at the impact area (BMX-style helmets). Helmet S3 was advertised as a multi-impact helmet despite not being certified, whereas all others were designated single-impact (B1-B6, S2, S4-S7) or unspecified (S1).