Differences in bicycle helmet performance under real-world impact conditions using standard and oblique test rigs

Virginia Tech
Institute for Critical Technology and Applied Science

Megan L. Bland, Craig McNally, Steven Rowson

Virginia Tech, Department of Biomedical Engineering and Mechanics

Virginia Tech – Wake Forest University Center for Injury Biomechanics

Introduction

- Cycling is the leading cause of sport-related head injuries in the US.[1]
- Bicycle helmets must comply with standards limiting peak linear acceleration (PLA) to <300 g in impact testing.
- Limitations of standards:
  - Pass-fail; do not provide data on which helmet designs offer better protection.
  - Test more severe impacts than those seen in typical cyclist accidents (~100 g).[2]
  - No testing at helmet rim, a common real-world impact location.[2,3]
  - Only measure PLA in simplified normal impacts, while real-world accidents are oblique and involve rotational acceleration, a major contributor to concussion.[4]

***Objective*: To investigate differences in protective capabilities of bicycle helmets under real-world conditions using standard normal and oblique impact rigs.**

Methods

Normal (standard) impacts

Oblique impacts

Ten helmet models were impacted on a standard drop rig with a flat anvil and on a custom oblique rig with a 30° anvil.

Impact Configurations

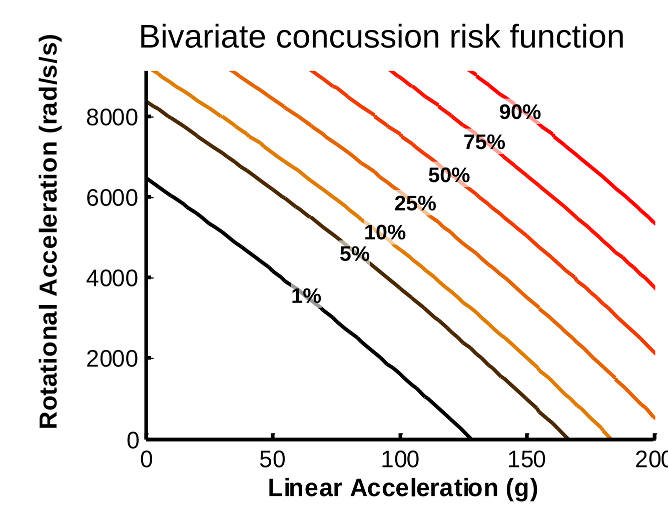
Location	Velocity
Frontal (rim)	Low
	High
Temporal	Low
	High

Common in real-world impacts

Low: average cyclist head impact

High: standard-specified for normal impacts, moderate for oblique impacts

4 configurations per test rig, each tested 4 times per helmet: **320 total tests**

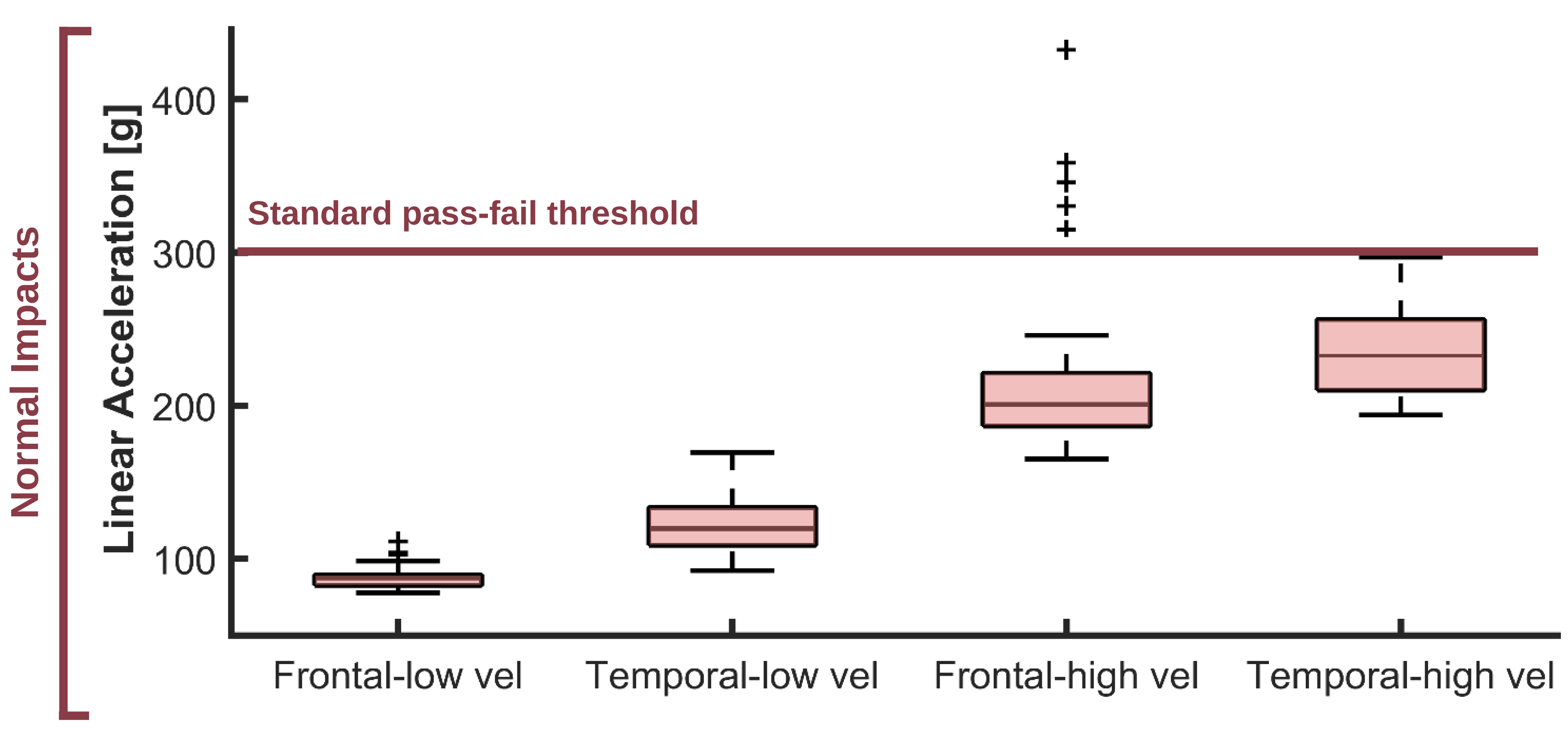


Data Analysis

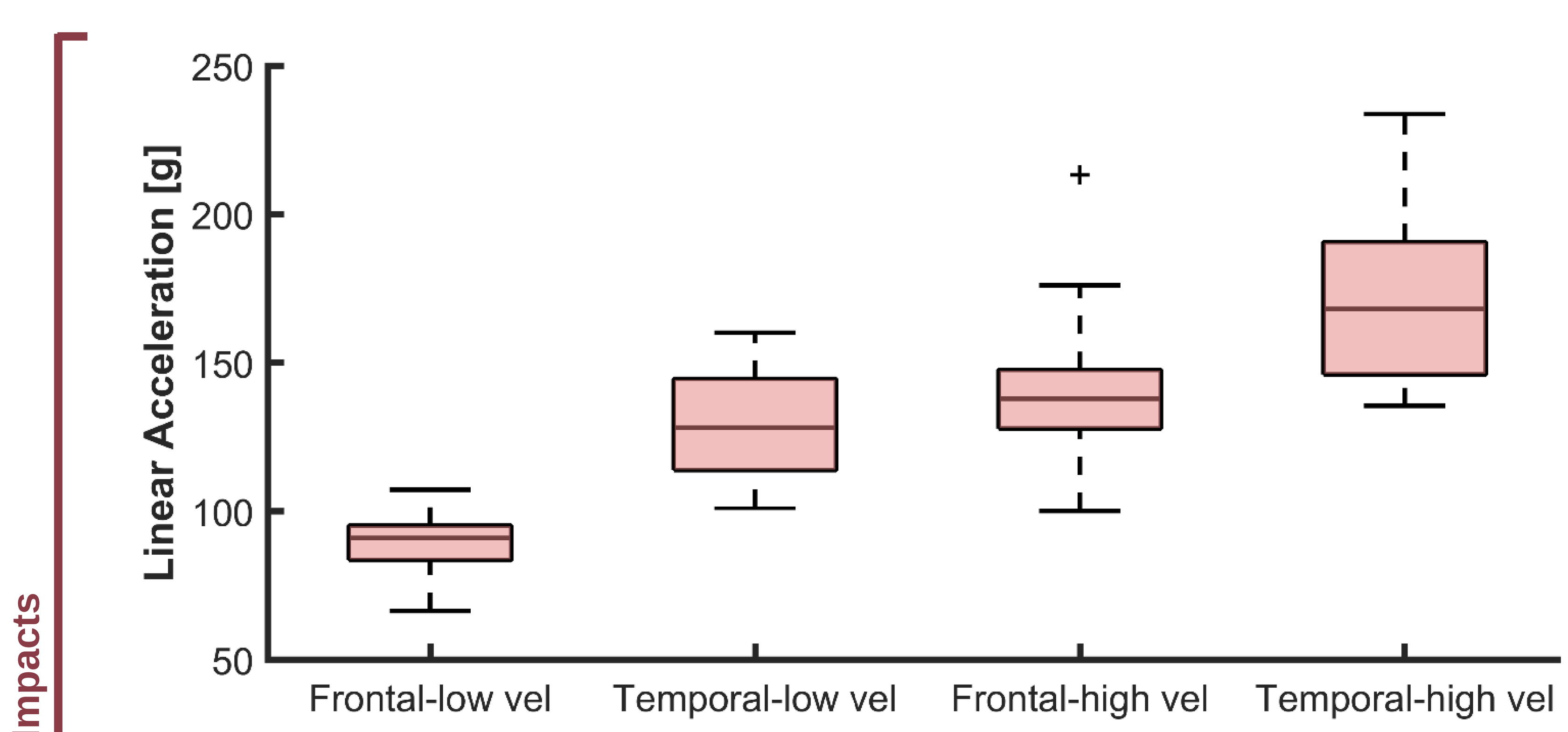
- Normal impacts: PLA
- Oblique impacts: PLA and peak rotational acceleration (PRA), concussion risk
- ANOVA, nonparametric correlations

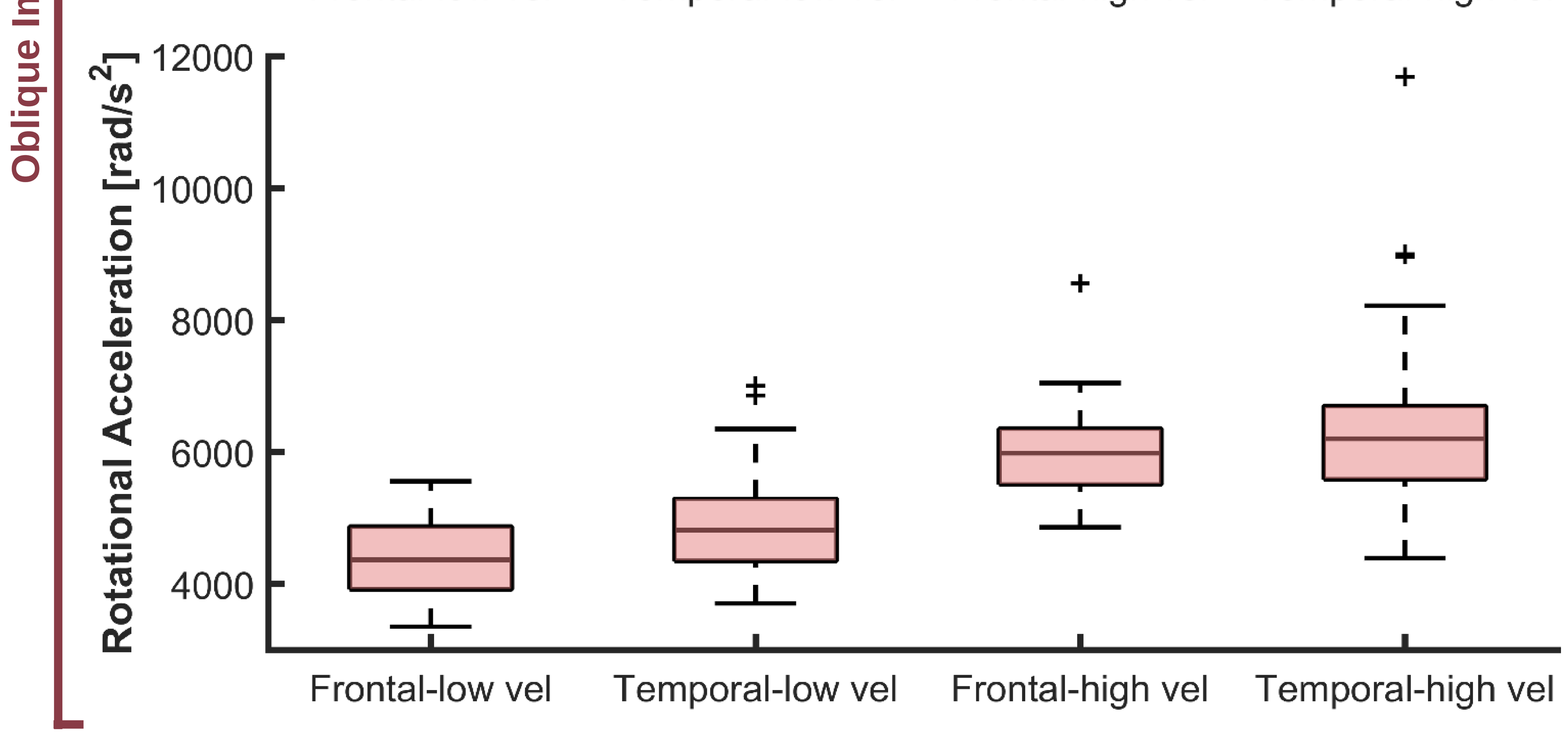
Bell Solar Flare (BSF) $40.00 | Bell Star Pro (BSP) $240.00 | Bell Super 2 MIPS (BMIPS) $155.00 | Catlike Whisper (CW) $234.99 | Giro Sutton MIPS (GMIPS) $234.99 | Giro Synthe (GS) $249.99 | Nutcase Watermelon (N) $69.99 | Smith Optics Overtake (SOO) $250.00 | Schwinn Thrasher (ST) $23.00 | S-Works Evade (SWE) $225.00

Results

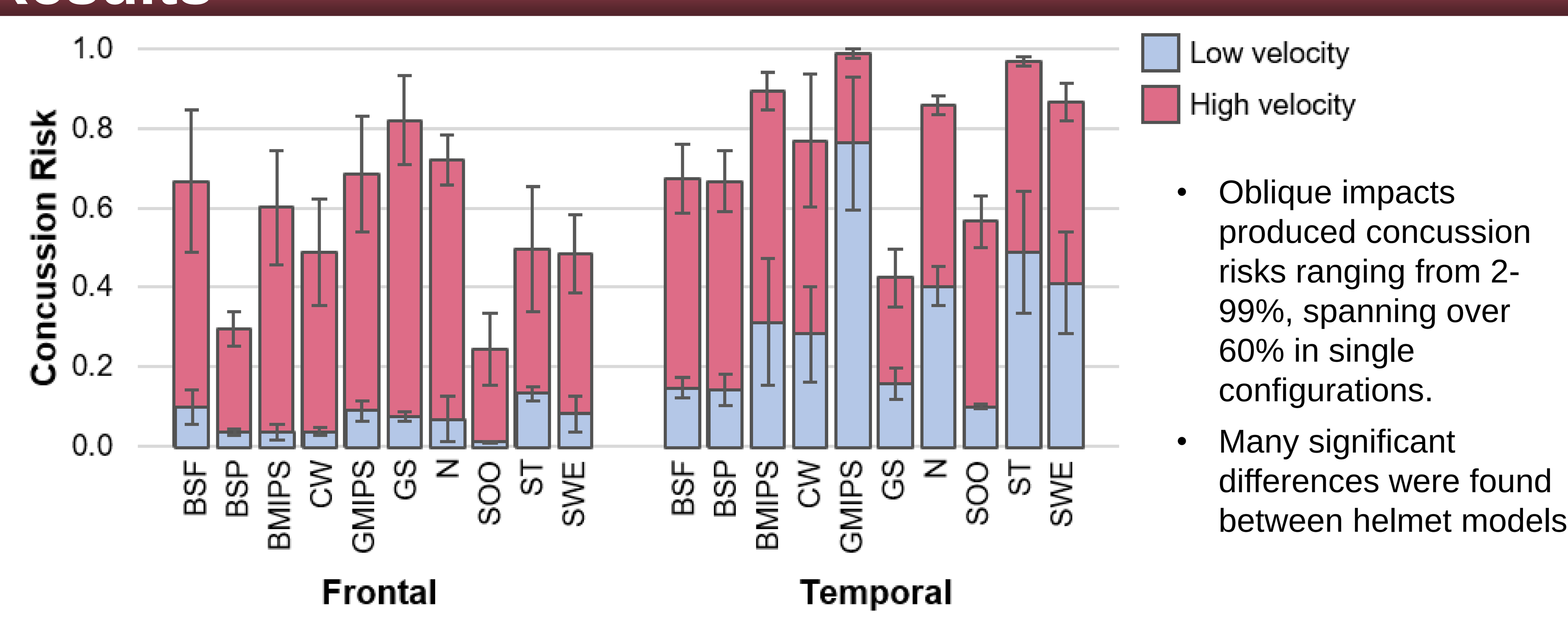


- PLA in normal impacts averaged 105±22 and 227±46 g at the low and high velocities.
- Temporal PLAs were higher, although two helmets bottomed out in the frontal-high velocity configuration and would have failed current standards.
- Many significant differences were found between helmet models.





- PLA in oblique impacts averaged 109±24 and 154±27 g at the low and high velocities, while PRA averaged 4.6±0.7 and 6.2±1.1 krad/s^2.
- Temporal PLAs were again higher than frontal, while PRA varied less by location.



- Oblique impacts produced concussion risks ranging from 2-99%, spanning over 60% in single configurations.
- Many significant differences were found between helmet models.

Normal Impacts (based on PLA)

Helmet	Summed Rank
BSP	10
SOO	10
BSF	14
GS	20
SWE	22
CW	23
BMIPS	26
ST	31
GMIPS	32
N	32

Best ↔ Worst

Oblique Impacts (based on concussion risk)

Helmet	Summed Rank
SOO	5
BSP	10
CW	18
GS	21
BMIPS	22
BSF	23
SWE	25
N	27
ST	33
GMIPS	36

- Helmet rank was summed across configuration to indicate overall performance.
- Rank was correlated within configurations and across test rig.
- Variations in PRA altered rank magnitude and order for oblique impacts.

Discussion

- Many significant differences in accelerations were found between helmet models. Oblique impacts showed considerable risk of concussion for some models.
- Temporal PLAs were generally higher than frontal PLAs, likely due to a larger radius of curvature at the temporal location, which produces larger contact areas and increases effective liner stiffness.
- There were several PLA outliers in the frontal-high velocity configuration for both impact types. This location is not included in standards testing, but is a common impact location in cyclist accidents.[2,3]
- Non-road helmets were generally ranked poorer, suggesting this style may offer inferior protection compared to road helmets.
- While helmet rank was similar across configuration and test rig, several helmets produced significantly greater PRAs and higher concussion risks, enhancing discrimination of overall performance.

Conclusions

- Significant differences exist in helmet performance under real-world conditions.
- Extreme PLAs were observed at the frontal location in the high-velocity condition, suggesting that standards testing should be expanded to include the helmet rim.
- There is clinical value in assessing helmet performance under oblique impacts, as these impacts reflect real-world accidents and enhance rank discrimination through the addition of rotational acceleration.
- These results can be used to inform standards testing and improve bicycle helmet safety.

Acknowledgements: Insurance Institute for Highway Safety

References: [1]AANS, "Sports-related Head Injury," 2014 [2]Williams, *Accid Anal and Prev*,1991 [3]Bourdet, *J Sports Eng & Tech*, 2012. [4]Gennarelli, TA et al., *SAE Tech Paper 720970*, 296-308, 1972

Presented at the 2017 Injury Biomechanics Symposium, Columbus, OH