2024 SAE Government-Industry Meeting, January 16-18, 2024, Washington, DC

NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Motorcycle Helmet Test Procedure Development and Repeatability Analysis

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Background

- All motorcycle helmets sold in the U.S. must comply with FMVSS No. 218 performance requirements. Performance tests in FMVSS No. 218 include an impact attenuation test, a quasi-static retention test, and a penetration test.
  - All three tests use a DOT standard headform
- NHTSA conducted research to evaluate test procedures for modified versions of the impact attenuation and retention tests, as well as tests in other standards.
  - The recorded performance of individual helmet makes and models relates solely to the studied test conditions and their associated criteria, and is not relevant to current FMVSS No. 218 requirements.
- This test series was a continuation of testing presented at the 2019 SAE Government-Industry Meeting*

* Nguyen, C., “NHTSA’S Motorcycle Helmet Testing Research Program”, SAE Government Industry Meeting, Apr 2019

Objectives

- Evaluate test procedures for modified versions of the impact attenuation and retention tests, as well as tests in other standards.
  - Evaluate test procedures for each test by applying them to a select sample of helmets
    - Impact attenuation test based on FMVSS No. 218
      - Use ASTM headforms
      - Reduce the maximum allowable acceleration of the headform from 400 g to 300 g
      - Eliminate the 4 ms dwell time requirement
    - Retention test based on FMVSS No. 218
      - Use ASTM headforms
    - Chin bar impact attenuation test based on BSI 6658
    - Positional stability test based on ASTM F1446-11a
    - Face shield impact test based on ECE R22
    - External rigid projection test based on ECE R22
  - Evaluate the repeatability of each test

Headforms

- DOT headforms are used in FMVSS No. 218
- ASTM full headforms include a continuous face, chin, and neck region. ASTM headforms are used in other testing standards

Headform Comparison

DOT ASTM Half ASTM Full

Headform Comparison					
DOT			ASTM		
Size	Mass	Circumference	**Size**	Mass	Circumference
Small	3.5 kg	490 mm	**A**	3.1 kg	495 mm
			C	3.6 kg	515 mm
			E	4.1 kg	535 mm
Medium	5.0 kg	560 mm	**J**	4.7 kg	575 mm
Large	6.1 kg	600 mm	**M**	5.6 kg	605 mm
			O	6.1 kg	625 mm

ASTM Headforms

Test Matrix

Tests were conducted in sequence in ambient conditions, with no additional pre-conditioning (such as solvents or UV).

Helmet Model	HJC F70	Bilt Vertex	Scorpion EXO Covert X	Shoei Neotec II	Schuberth M1 Pro	Shark Street Drak
Type	Complete	Complete	Modular	Modular	Full	Full
Helmet Size	M	L	M	XL	XL	XL
Headform Size	J	J	J	M	M	M
# of Repeats	5	5	5	5	15	15
Tests Performed	• DOT Impact Attenuation • DOT Retention • BSI Chin Bar	• DOT Impact Attenuation • DOT Retention • BSI Chin Bar	• DOT Impact Attenuation • DOT Retention • BSI Chin Bar	• DOT Impact Attenuation • DOT Retention • BSI Chin Bar	• ASTM Positional Stability • ECE Face Shield • ECE Rigid Projection	• ASTM Positional Stability • ECE Face Shield • ECE Rigid Projection

Helmets Tested

Complete

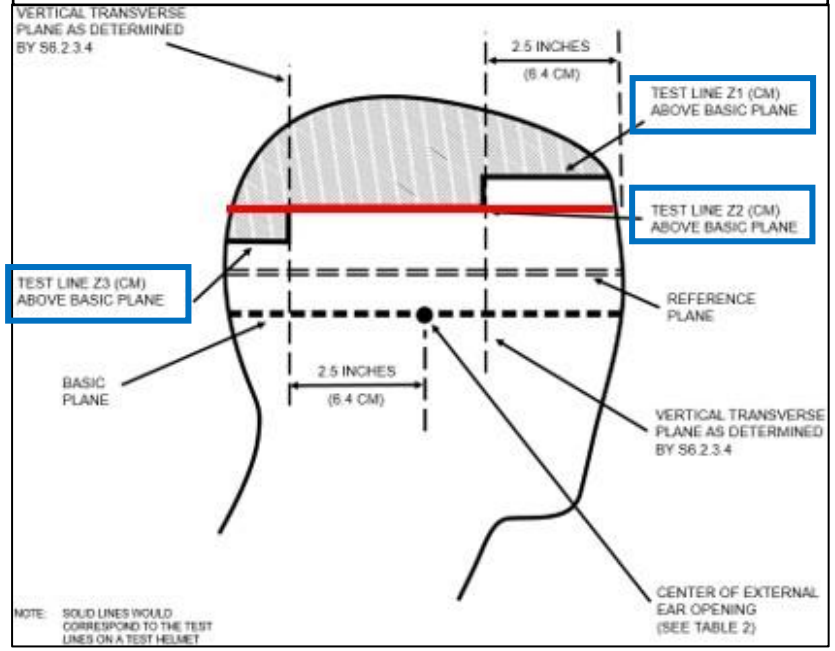
Modular

Full

Discrete Size Measurements

- Followed the discrete size measurement methodologies developed by VRTC* to select the appropriate size ASTM headform for testing.
  - The handheld scissor tool was used for this testing.

Test Reference Line



Handheld Scissor Tool

Test Reference Line

* Wietholter, K., & Rains, C. (2023, September). *Development of discrete size measurement methodologies for motorcycle helmets* (Report No. DOT HS 813 305). National Highway Traffic Safety Administration.

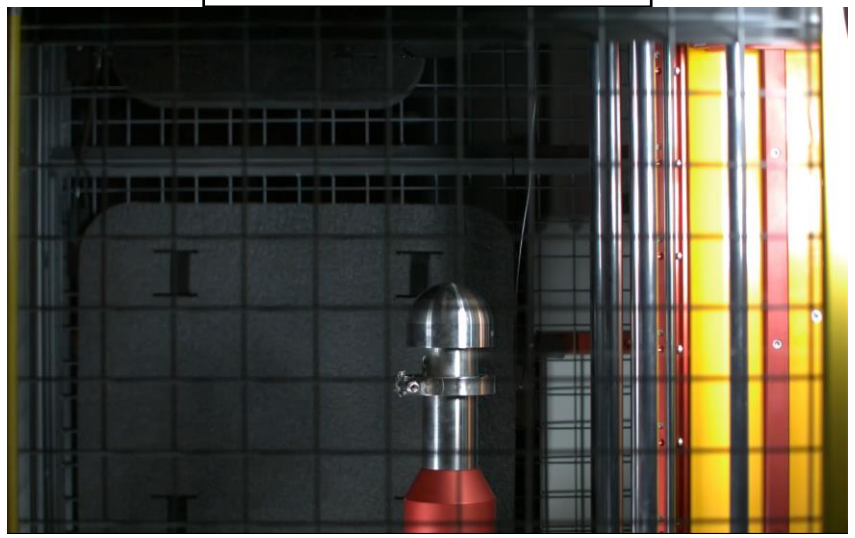
Impact Attenuation Test

Based on FMVSS No. 218, using ASTM headforms

- **Test Set-Up**
  - Each helmet was tested eight times
    - Flat and hemispherical anvils
    - Two locations per anvil
    - Two impacts per location
- **Data Collection**
  - Recorded high-speed video
  - Recorded acceleration of the headform
- **Performance Criteria**
  - Peak acceleration could not exceed 300 g
  - Dwell time could not exceed a cumulative duration of 2 ms above 200 g

Flat Anvil

Hemispherical Anvil



Impact Attenuation Test

Based on FMVSS No. 218, using ASTM headforms

- FMVSS No. 218 specifies that the impact sites can be at any point on the area above the test line and separated by a distance not less than one-sixth of the maximum circumference of the helmet in the test area.
- The four impact locations for this series were:
  - Flat anvil
    - Right front
    - Left rear
  - Hemispherical anvil
    - Right rear
    - Left front
  - All locations were at the midpoint between the midsagittal plane and the transversal plane and 65 mm above the test line

Retention Test

Based on FMVSS No. 218, using ASTM headforms

- **Test Set-Up**
  - Each helmet was tested once
- **Data Collection**
  - Recorded real-time video
  - Recorded load on retention system throughout the duration of the test (not used as performance criteria)
- **Performance Criteria**
  - The retention system must hold the loads without separation
  - The adjustable portion of the retention system could not move more than 2.5 cm

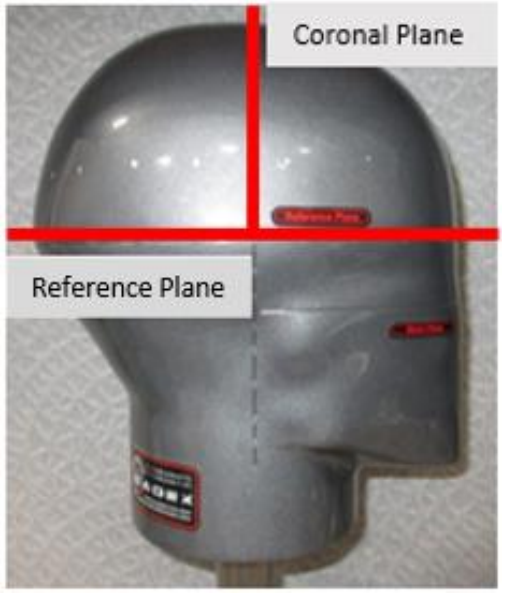
Chin Bar Test

Based on BSI 6658, with minor modifications

- **Test Set-Up**
  - Each helmet was tested once
- **Data Collection**
  - Recorded high-speed video
  - Recorded acceleration of the striker
- **Performance Criteria**
  - Peak acceleration could not exceed 300 g

Positional Stability Test

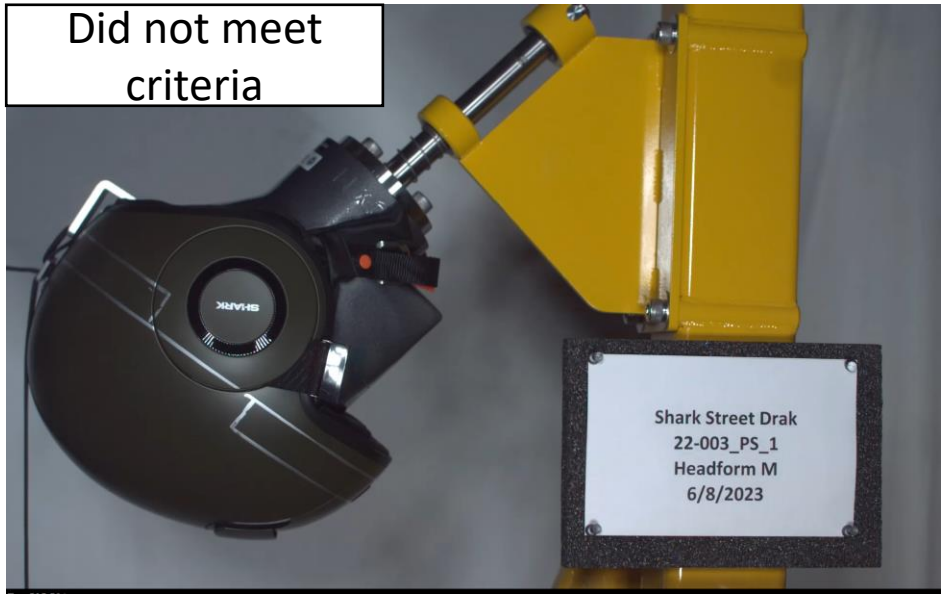
Based on ASTM F1446-11a, with minor modifications



- **Test Set-Up**
  - Each helmet was tested once
- **Data Collection**
  - Recorded high-speed video
  - No data was recorded
- **Performance Criteria**
  - The helmet retention system must remain intact
  - No part of the coronal plane above the reference plane could be visible during the test

Met criteria

Did not meet criteria



Face Shield Test

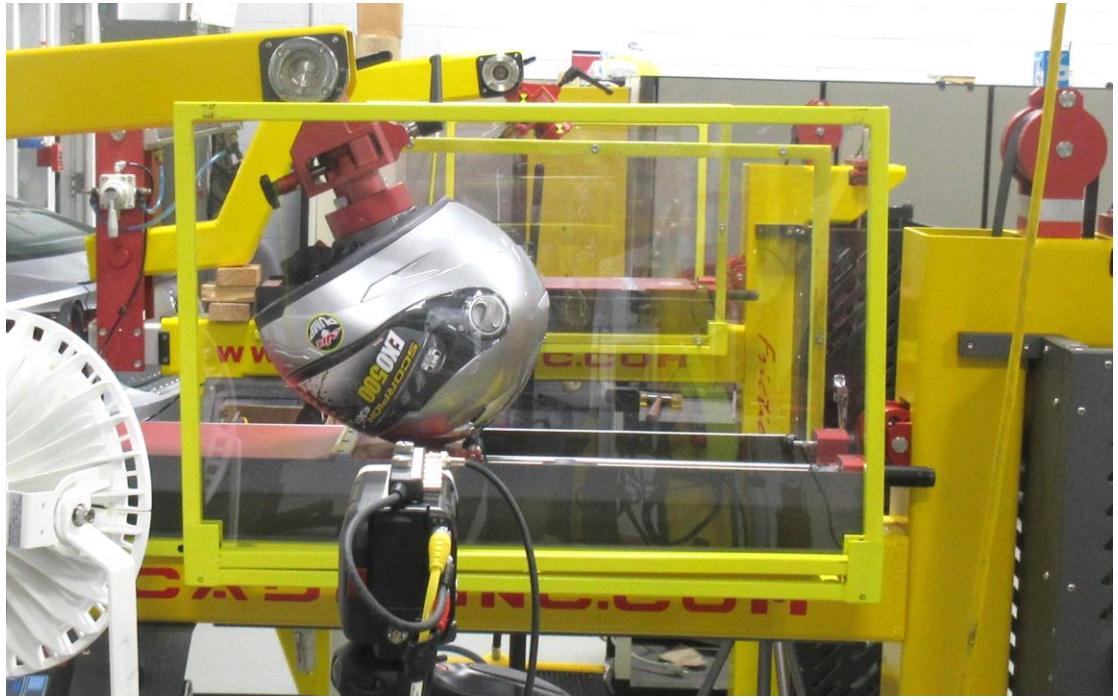
Based on ECE R22, with minor modifications

- **Test Set-Up**
  - Each helmet was tested once
- **Data Collection**
  - Recorded high-speed video
  - No data was recorded
- **Performance Criteria**
  - No sharp splinters could be produced (any segment having an angle less than 60 degrees)
  - The striker could not contact the headform

Rigid Projection Test

Based on ECE R22, with minor modifications

- **Test Set-Up**
  - One test was conducted on each projection
- **Data Collection**
  - Recorded high-speed video
  - Recorded velocity of carriage (not used as performance criteria)
- **Performance Criteria**
  - The projection must shear away, detach, or otherwise not prevent the bar from sliding past the projection



Rigid Projection Tests

- Rigid projections were located:
  - Schuberth M1 Pro
    - Top vent
    - Rear rib
  - Shark Street Drak
    - Top vent

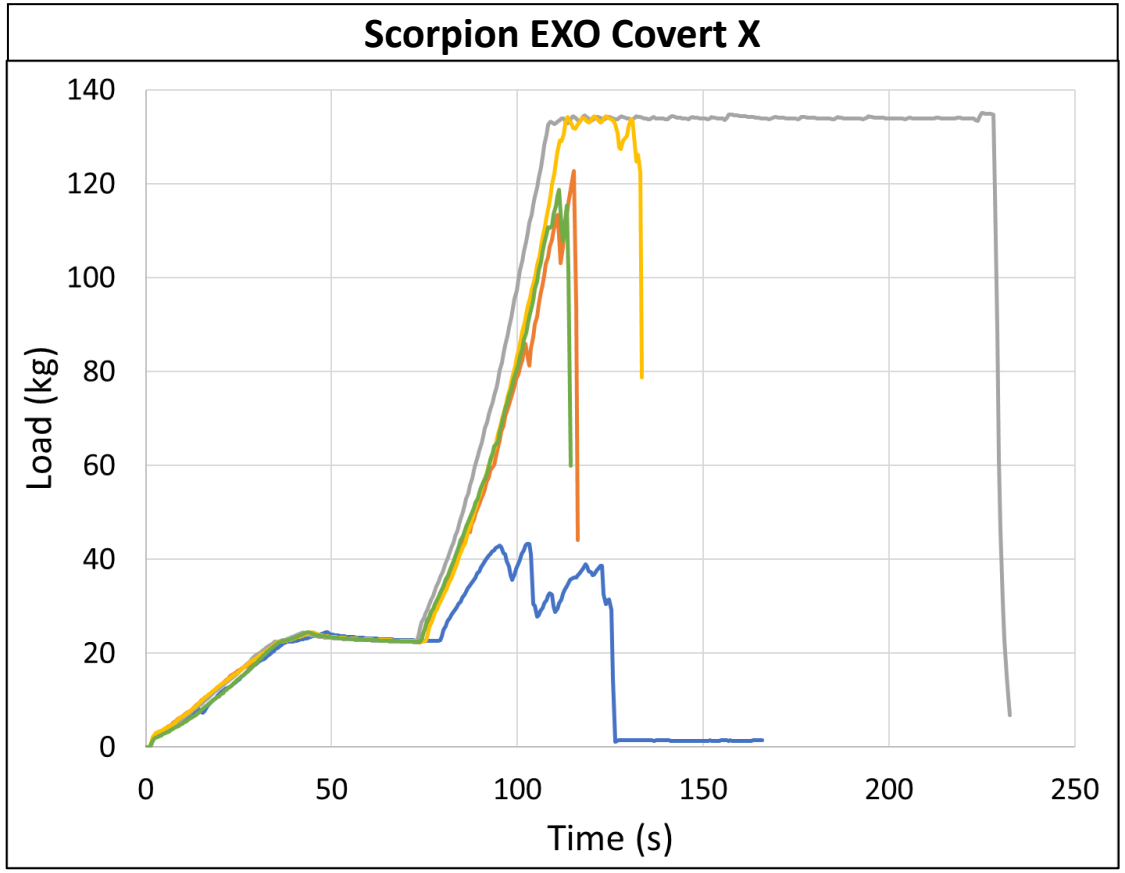
Results – Impact Attenuation

- Peak Acceleration: All helmets met the criteria
- Dwell Time: All helmets met the criteria

Helmet Model	Helmet Number	Impact Attenuation															
		Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		Test 7		Test 8	
		Peak Accel	Dwell Time	Peak Accel	Dwell Time	Peak Accel	Dwell Time	Peak Accel	Dwell Time	Peak Accel	Dwell Time	Peak Accel	Dwell Time	Peak Accel	Dwell Time	Peak Accel	Dwell Time
HJC F70	22-044																
	22-045																
	22-046																
	22-047																
	22-048																
Bilt Vertex	22-051																
	22-052																
	22-053																
	22-054																
	22-055																
Scorpion EXO Covert X	22-030																
	22-031																
	22-032																
	22-033																
	22-034																
Shoei Neotec II	22-037																
	22-038																
	22-039																
	22-040																
	22-041																

Results – Retention

- Adjustment Movement: All helmets met the criteria
- Strap Detachment:
  - One strap fully detached
  - Three straps partially detached



Strap Fully Detached

Strap Partially Detached

Helmet Model	Helmet Number	Retention	
		Straps Detach	Adjustment Movement
HJC F70	22-044		
	22-045		
	22-046		
	22-047		
	22-048		
Bilt Vertex	22-051		
	22-052		
	22-053		
	22-054		
	22-055		
Scorpion EXO Covert X	22-030		
	22-031		
	22-032		
	22-033		
	22-034		
Shoei Neotec II	22-037		
	22-038		
	22-039		
	22-040		
	22-041		

Results – Chin Bar

- Peak Acceleration:
  - One helmet did not meet the criteria

Helmet Model	Helmet Number	Chin Bar
		Peak Accel
HJC F70	22-045	
	22-046	
	22-047	
	22-048	
	22-049	
Bilt Vertex	22-051	
	22-052	
	22-053	
	22-054	
	22-055	
Scorpion EXO Covert X	22-030	
	22-031	
	22-032	
	22-033	
	22-034	
Shoei Neotec II	22-037	
	22-038	
	22-039	
	22-040	
	22-041	

Results – Positional Stability

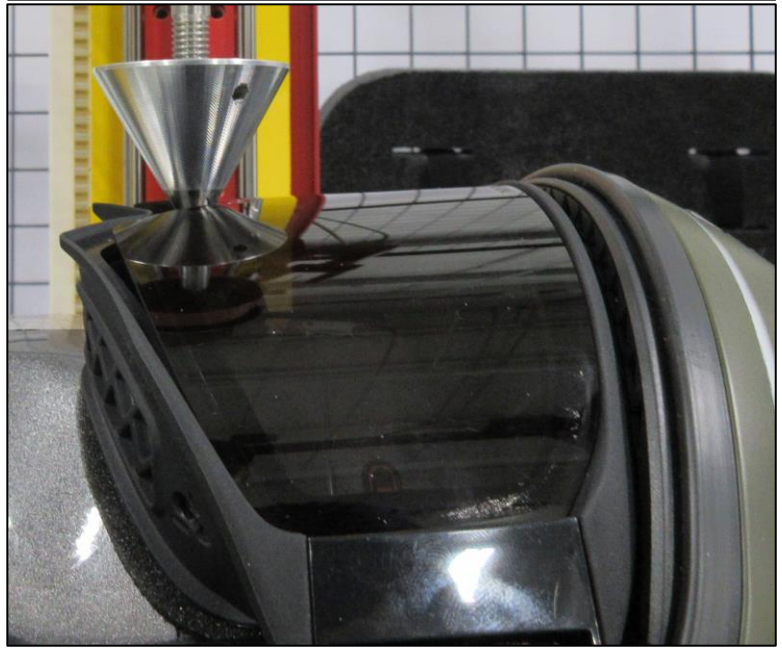
- Helmet stays on headform:
  - One helmet did not meet the criteria

Helmet Model	Helmet Number	Positional Stability
		Stays on Headform
Schuberth M1 Pro	22-010	
	22-011	
	22-012	
	22-013	
	22-014	
	22-015	
	22-016	
	22-017	
	22-018	
	22-019	
	22-020	
	22-021	
	22-022	
	22-023	
	22-024	
Shark Street Drak	22-001	
	22-002	
	22-003	
	22-004	
	22-005	
	22-006	
	22-007	
	22-008	
	22-009	
	22-058	
	22-059	
	22-060	
	22-061	
	22-062	
	22-063	

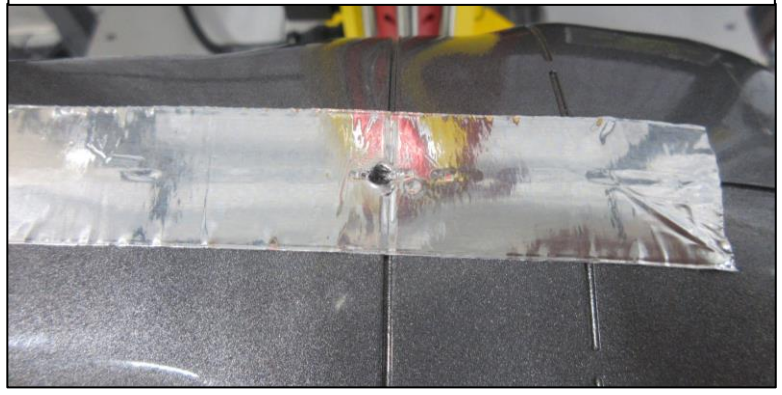
Results – Face Shield

- Small Fragments: All helmets met the criteria
- Headform Contact:
  - All Shark Street Drak helmets allowed the striker to contact the headform

Striker Penetrating Face Shield



Damage to Contact Tape on Headform



Helmet Model	Helmet Number	Face Shield	
		Small Fragments	Headform Contact
Schuberth M1 Pro	22-013		
	22-014		
	22-015		
	22-016		
	22-017		
	22-018		
	22-019		
	22-020		
	22-021		
	22-022		
	22-023		
	22-024		
	22-025		
	22-026		
	22-027		
Shark Street Drak	22-001		
	22-002		
	22-003		
	22-004		
	22-005		
	22-006		
	22-007		
	22-008		
	22-009		
	22-058		
	22-059		
	22-060		
	22-061		
	22-062		
	22-063		

Results – Rigid Projection

- Shear bar passes over projection: All helmets met the criteria

Helmet Model	Helmet Number	Rigid Projection	
		Top Vent	Rear Rib
Schuberth M1 Pro	22-010		
	22-011		
	22-012		
	22-013		
	22-014		
	22-015		
	22-016		
	22-017		
	22-018		
	22-019		
	22-020		
	22-021		
	22-022		
	22-023		
	22-024		
Shark Street Drak	22-001		
	22-002		
	22-003		
	22-004		
	22-005		
	22-006		
	22-007		
	22-008		
	22-009		
	22-058		
	22-059		
	22-060		
	22-061		
	22-062		
	22-063		

Repeatability

- Impact Attenuation (only peak acceleration) and Chin Bar
  - Repeatability was evaluated using %CV and Sigma to limit (SigmaL)
    - If the %CV was below 10%, the test was deemed repeatable
    - SigmaL calculated the number of standard deviations between the average response and the performance limit ($^{Performance\ limit - Average}/_{Standard\ deveiation}$)
      - For this analysis, if SigmaL was more than two standard deviations, the responses were considered far below the performance limit, and therefore the measured variation would not be the determining factor for whether the helmet would meet the performance criteria
  - Performed a one-way ANOVA
    - Grouped the five tests with each helmet model together and compared to the other models
    - We would expect the four helmets to have different results
      - If the p-value was above 0.05, that would indicate that variation between repeat tests might be overshadowing the differences we expect between the helmet models
- Retention, Positional Stability, Face Shield, and Rigid Projection
  - Repeatability was evaluated by consistency of test results relative to the performance criteria. If all or almost all of the tests met the requirement or did not meet the requirement, the repeatability was deemed acceptable

Repeatability – Impact Attenuation

Peak Acceleration

- 1/32 %CVs was above 10%
- The one elevated %CV did not correspond with a SigmaL of less than 2

Performance limit
Peak Acceleration: 300g

		Flat Anvil				Hemisperical Anvil			
		Right Front		Left Rear		Right Rear		Left Front	
		Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
HJC F70	Average	155.4	189.0	145.9	169.5	87.5	95.7	84.6	96.8
	St. Dev.	7.5	5.2	4.5	2.9	9.9	6.0	3.7	6.5
	%CV	4.8	2.7	3.1	1.7	11.3	6.2	4.4	6.7
	SigmaL	19.2	21.4	34.5	45.4	21.5	34.3	58.3	31.2
Bilt Vertex	Average	162.9	199.3	135.5	168.1	84.3	111.2	96.0	110.3
	St. Dev.	6.0	6.7	4.5	6.7	2.9	9.4	3.8	5.9
	%CV	3.7	3.3	3.3	4.0	3.4	8.4	3.9	5.3
	SigmaL	22.7	15.1	36.5	19.6	75.3	20.1	53.9	32.1
Scorpion EXO Covert X	Average	152.6	179.4	182.7	197.6	91.2	94.3	82.8	84.3
	St. Dev.	12.5	11.2	10.6	14.4	4.9	6.0	3.6	3.5
	%CV	8.2	6.2	5.8	7.3	5.4	6.4	4.3	4.2
	SigmaL	11.8	10.8	11.0	7.1	42.3	34.2	60.9	60.9
Shoei Neotec II	Average	154.1	178.8	173.8	196.2	109.7	114.2	102.2	108.3
	St. Dev.	4.7	8.1	9.7	7.2	5.3	5.3	6.1	1.8
	%CV	3.0	4.5	5.6	3.7	4.8	4.7	6.0	1.7
	SigmaL	31.2	15.0	13.0	14.4	36.2	35.0	32.3	103.9

Repeatability – Impact Attenuation

Only one impact had a p-value above 0.05, indicating that variability within the repeated tests was small enough to still statistically detect the differences between the helmet models.

	Right Front		Left Rear		Right Rear		Left Front	
	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2	Impact 1	Impact 2
p-value	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

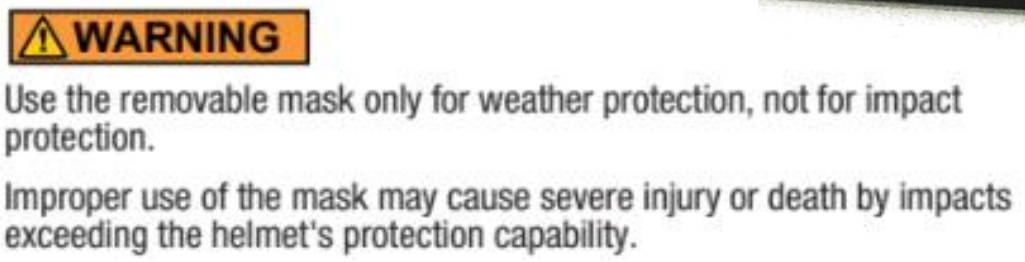
Repeatability – Chin Bar

Peak Acceleration

- 1/4 %CVs was above 10%
- The corresponding SigmaL was less than 2
  - This shows that there was variability with the Scorpion EXO Covert X and this variability could influence whether a test met or did not meet the performance criteria due to the proximity of the results to the performance limit
- 1/5 chin bar tests with the Scorpion EXO Covert X did not meet this requirement
- This helmet displays a sticker on the chin bar that says “Does not protect chin from impacts”

HJC F70	Average	108.8
	St. Dev.	4.7
	%CV	4.3
	SigmaL	41.0
Bilt Vertex	Average	114.9
	St. Dev.	6.9
	%CV	6.0
	SigmaL	27.0
Scorpion EXO Covert X	Average	268.1
	St. Dev.	33.4
	%CV	12.5
	SigmaL	1.0
Shoei Neotec II	Average	134.9
	St. Dev.	13.4
	%CV	9.9
	SigmaL	12.3

Performance limit
Peak Acceleration: 300g



Repeatability – Chin Bar

P-value was less than 0.05, indicating that variability within the repeated tests was small enough to still statistically detect the differences between the helmet models.

Summary

- Test procedures were evaluated for each test and applied to a select sample of helmets
  - Used ASTM headforms in the impact attenuation and retention tests
  - Performed the impact attenuation test with the stated changes to the performance criteria
  - Performed the chin bar impact attenuation test, positional stability test, face shield impact test, and external rigid projection test per the reference standard with minor modifications

Summary

- Evaluated the repeatability of each test
  - Overall, the results were repeatable

Test	Performance Criteria	Repeatability Result
Impact Attenuation	Peak Accel	✓ 31/32 %CVs below 10% ✓ Corresponding SigmaL above 2 ✓ 7/8 p-values below 0.05
	Dwell Time	✓ All helmets met the requirement
Retention	Strap Detachment	✓ 4/5 Scorpion EXO Covert X helmets did not meet the requirement ✓ All other helmets did meet the requirement
	Strap Adjustment Movement	✓ All helmets met the requirement
Chin Bar	Peak Accel	X 3/4 %CVs below 10% X Corresponding SigmaL below 2 ✓ p-value below 0.05
Positional Stability	Stays on Headform	✓ 1/15 Shark Street Drak helmets did not meet the requirement ✓ All other helmets did meet the requirement
Face Shield	Small Fragments	✓ All helmets meet the requirement
	Headform Contact	✓ All Shark Street Drak helmets did not meet the requirement ✓ All Schuberth M1 Pro helmets did meet the requirement
Rigid Projection	Shear Bar Passes Over Projection	✓ All helmets met the requirement

Thank you

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