Impact Dynamics of Football Helmets on Various Surfaces

Halstead, Kramer, Schnider, Drew et al - Safety in American Football

OBJECTIVES

The following report consists of data collected from two different testing environments as well as different testing procedures. The overall objective of the testing was to show the performance of a NOCSAE compliant football helmet in realistic impacts with both the playing surface and helmets worn by opposing players. Each of the following sections of this report will include two parts describing Helmet/Turf testing and Helmet/Helmet testing.

A. Helmet/Turf Testing

The primary objective of this testing was to demonstrate the performance of NOCSAE football helmets when tested on the field of play. This would include impacting on the actual playing surface at similar conditions to those experienced by players during similar game conditions. Testing included vintage helmets as well as those which were in new condition.

B. Helmet/Helmet Testing

The primary objective of this testing was to determine the performance of the NOCSAE football helmet when tested in helmet to helmet impacts. This testing was done on both the NOCSAE and ASTM test rigs, using other NOCSAE compliant helmets as the impacted surface in place of the standard impacting anvils. Standard NOCSAE and/or ASTM procedures were used in conjunction with the special test set up that was employed to achieve impact conditions.

All impacting was carried out at 12+MPH. This is the speed calculated from previous experiments using college football players. It is not our intention to represent that as a peak velocity.

TEST EQUIPMENT

A. Helmet/Turf Testing

Standard NOCSAE equipment was modified so as to make it portable and allow direct impacts to the turf. The system was rigidly affixed to a steel base plate, which served to emulate the NOCSAE based plate. This was needed for pre-test calibration only and was removed when testing of the helmet began.

B. Helmet/Helmet Testing

Standard NOCSAE equipment was used as set up and typically used in the laboratory environment. Pre test equipment checks showed it to be the proper type and installed in such a way so as to provide the conditions appropriate to the NOCSAE test. ASTM testing was performed on a standard monorail test rig. The ASTM test apparatus was in good repair and met all the requirements as set forth in ASTM Standards F-429 & F-717 respectively. In addition, the NOCSAE portion of this testing also included a second instrumented NOCSAE head model mounted to a Sierra Hybrid II Neck mounted to a 50 lb. cast aluminum torso. This headform was calibrated in the normal NOCSAE fashion. Still a third NOCSAE headform was used in this testing. It was not instrumented. In the ASTM portion of this test a second headform was also used. The DOT size "C" head model was used in the setup, in addition to the ISO size "J" headform as specified in the ASTM procedure.

TESTING ENVIRONMENT

A. Helmet/Turf Testing

Testing was performed at "Husky Field". On arrival at the field conversations with the grounds keepers verified that field conditions were average. I was able to determine that the field was watered via automatic sprinkler between 10:20 PM and 10:40 PM for an 18-minute cycle the previous evening. This is the normal routine. The period of time from the last watering of the field prior to testing was approximately 16 hours. At least eight hours of this exposure was during the sunshine hours. The ground appeared dry to the eye and touch at the time of testing.

B. Helmet/Helmet Testing

Testing was performed in a laboratory where the temperature and humidity were 75°F and 50% respectively.

EQUIPMENT SET UP & CALIBRATION

A. Helmet/Turf Testing

After arriving and setting up the "NOCSAE" system it was approximately 2:15 PM. The system was set up in the area of the 15 yard line and to the right of center on the field when looking at the north goal post. Proper cable tension and carriage alignment were verified. The electronics were checked via NOCSAE pulse through procedures, which resulted in the proper voltage/SI output. This demonstrated that the electronic systems were functioning properly. NOCSAE head form MB-2 size 7 1/4 was attached to the drop carriage. The head form was equipped with a triaxial accelerometer, serial number PCB-303m134 from PCB electronics in accordance with NOCSAE standards. Severity Index analyzer serial number 248

was connected to the accelerometer. With the base plate in place and the normal NOCSAE anvil and MEP installed, a series of calibration drops were made.

The following calibration data was obtained:

18" CALIBRATION DROPS ON MEP IN FRONT POSITION

DROP #	LOCATION	SI TARGET (+\-5%)	SI RESULTS
1-F	FRONT	737 (700-774)	735
2-F	FRONT	737 (700-774)	737
3-F	FRONT	737 (700-774)	736
1-S	SIDE	759 (721-796)	749
2-S	SIDE	759 (721-796)	744
3-S	SIDE	759 (721-796)	749
1-T	TOP	841 (799-883)	833
2-T	TOP	841 (799-883)	837
3-T	TOP	841 (799-883)	826

This calibration data shows that the system fell well within the Round Robin data of 1980, which is the NOCSAE calibration target. At the completion of the calibration the base plate was removed leaving a clear path to the turf below. This enabled the testing to be conducted on the natural surface of "Husky Field". This would be a very good approximation of the impact and a resulting SI that would be experienced in actual field play.

R. **Helmet/Helmet Testing**

NOCSAE

Proper cable tension and carriage alignment were verified. The electronics were checked via NOCSAE pulse through procedures, which resulted in the proper voltage/SI output. This demonstrated that the electronic systems were functioning properly. NOCSAE head form JBM-82 size 7 1/4 was attached to the drop carriage. The head form was equipped with a triaxial accelerometer from PCB electronics in accordance with NOCSAE standards. The Severity Index analyzer was connected to the accelerometer. With the normal NOCSAE anvil and MEP installed, a series of calibration drops were made.

The following NOCSAE calibration data was obtained:

18" CALIBRATION DROPS ON MEP IN FRONT POSITION

DROP #	LOCATION	SI TARGET (+\-5%)	SI RESULTS
1-F	FRONT	737 (700-774)	727
2-F	FRONT	737 (700-774)	749
3-F	FRONT	737 (700-774)	741
1-S	SIDE	759 (721-796)	755
2-S	SIDE	759 (721-796)	754
3-S	SIDE	759 (721-796)	768
1-T	TOP	841 (799-883)	847
2-T	TOP	841 (799-883)	840

3-T	TOP	841 (799-883)	846

This calibration data shows that the system fell well within the Round Robin data of 1980, the NOCSAE calibration target. NOCSAE headform model M-33 was calibrated in the same manner prior to testing. The average of three drops in each of the calibration positions was calculated. The following data was recorded:

Front	734
Side	758
Top	839

This demonstrated that the second NOCSAE headform, accelerometer and SI analyzer to be used in this test was also within the Round Robin data as required.

ASTM

ASTM pre-test system check was performed in accordance with ASTM standards using a certified spherical impactor and MEP. ASTM system check showed all system components to be in specification. The impactor and MEP were supplied and certified by US Testing Inc.

System check results were as follows:

g's	Impact Velocity
393	5.44 meters/sec.
392	5.44 meters/sec.
393	5.48 meters/sec.

This demonstrated proper equipment function.

HELMET SELECTION

A. Helmet/Turf Testing

Testing was performed using five helmets. Helmet 1 was a Riddell PAC-3 size 7 1/4. The components dated as follows: Front Pad 6/80, Top Pads 3/78, Back Pad 8/84, "Neck" Pad 7/78, all pads size "A". Helmet 2 was a 12/69 Riddell Micro-Fit size 7 1/8 - 7 3/4, with a two point chinstrap (all other helmets had a three point chin strap system). Helmet 3 was a Pro Air II size 7 1/8 - 7 3/4, serial number 691298. Helmet 4 was a Riddell M-155 7 1/4 - 7 3/4. Helmet 5 was a Riddell PAC-3 7 1/4 with vintage components similar to Helmet 1.

B. Helmet/Helmet Testing

Testing was performed using three helmets. A Silver PAC-3 size 7 1/4, components dated as follows: Shell 11/80, Front Pad 11/80, Top Pads 10/79, Back Pad 6/79, "Neck" Pad 2/82, all pads size "A". The PAC-3 had been tested previously. The other helmets consisted of a White WD-1 7 1/4 and Red Air

Power 7 1/8 - 7 3/4. The WD-1 was a 1992 production helmet. The Air Power was pre 1984.

TEST DATA

A. Helmet/Turf Testing

At approximately 2:30 PM we dropped the calibrated head form from 18 inches onto the surface of "Husky Field".

18" PRE-TEST DROP ONTO TURF

DROP NO.	LOCATION	SI RESULTS
1-F	FRONT	146

This was the first indication that the ground was somewhat more compliant than the standard NOCSAE test anvil/MEP.

At 2:44 PM, with the shaded field temperature at 89 F, the temperature in the direct sunlight was variable from 96 - 108 F. We placed a Riddell PAC-3 size 7 1/4 (which we marked as Helmet 1) onto the MH-2 test head form. This particular helmet had all size "A" pads. The front pad was dated 6/80, top pad set 3/78, upper back pad 8/84, "neck" pad 2/78. This helmet had been conditioned to a temperature of 96 F. It is believed this temperature would closely approximate the temperature of the helmets in use.

We then began a series of tests on the helmet.

HELMET 1 TEST 1-11 @ 60"

TEST NO.	LOCATION	SI RESULTS	COMMENTS
1	FRONT	546	
2	FRONT	734	SOME COMPRESSION OF SOIL
3	FR BOSS	497	
4	FR BOSS	645	
5	SIDE	436	2:55 PM
6	SIDE	505	
7	RR BOSS	645	
8	RR BOSS	670	
9	REAR	993	SOIL COMPRESSION SIGNIFICANT
10	REAR	1006	DEEP DENT IN SOIL 3:12 PM
11	REAR	694	NEW POSITION ON TURF 3:16 PM

Test 9 and 10 were conducted on soil, which had compressed to a considerable degree. Therefore, testing was conducted on a different position on the field. This was the first indication that the compression of the turf was a large factor in the testing. It was decided to test two of the remaining helmets once in each position.

This was done in an effort to minimize the number of large dents in the playing surface. Relocating the test rig after each impact was also considered but, this would have resulted in large variability in the impact surface. Testing each helmet in the same location kept the data relative. Helmet 1 was actually subjected to the most severe test conditions.

In the accompanying graphs, the first impacts of Helmet 1 were used as data points. In the case of the rear, the third test of that position (the first on "virgin" turf) was averaged with test 33. Test 33 was a similar vintage PAC-3 impacted in the rear.

Upon completion of test 11, a different helmet was similarly tested. Helmet 2 was a 12/69 Riddell Micro-Fit size 7 1/8 - 7 3/4, with two point chin strap; it was tested at ambient conditions. All other helmets had a three-point chinstrap system.

HELMET 2 TEST 12-16 @ 60"

TEST NO.	LOCATION	SI RESULTS	COMMENTS
12	FRONT	815	SAME TURF AS TEST 11 3:35 PM
13	FR BOSS	790	
14	SIDE	XXX	NO TRIGGER
14A	SIDE	480	3:43 PM
15	RR BOSS	528	
16	REAR	797	3:46 PM TEMP IN SHADE 83°F

Upon completion of test 16 a third helmet was similarly tested. Helmet 3 was a Pro Air II 7 1/8 - 7 3/4, serial number 691298. Helmet temperature was 90 - 92 F. The exact age of this helmet can be determined from the serial number; it would be considered new.

HELMET 3 TEST 17-21 @ 60"

TEST NO.	LOCATION	SI RESULTS	COMMENTS
17	FRONT	609	NEW TURF FROM TEST 16 3:51 PM
18	FR BOSS	790414	
19	SIDE	XXX315	8:58 PM
19A	SIDE	480350	SECOND DROP TO SEE EFFECT OF SOIL COMPRESSION
20	RR BOSS	528519	4:00 PM
21	REAR	797650	

Upon completion of test 21 a fourth helmet was similarly tested. Helmet 4 was a Riddell M-155 7 1/4 - 7 3/4. Helmet temperature was 97 F. The exact age of this helmet can be determined from the mold clock; it would be considered new. This helmet was tested twice in each position to supply a base of data to compare to the first helmet tested.

HELMET 4 TEST 22-32 @ 60"

TEST NO.	LOCATION	SI RESULTS	COMMENTS
22	FRONT	618	4:10 PM
23	FRONT	657	
24	FR BOSS	486	
25	FR BOSS	588	4:21 PM
26	SIDE	XXX	NO TRIGGER
26A	SIDE	461	
27	SIDE	444	THIRD IMPACT
28	RR BOSS	556	SOIL COMPRESSION SIGNIFICANT
29	RR BOSS	611	4:30 PM
30	REAR	824	
31	REAR	792	
32	REAR	593	NEW TURF LOCATION

Upon completion of test 32 a fifth helmet was similarly tested. Helmet 5 was a Riddell PAC-3 7 1/4. Helmet temperature was 102 F at the neck and 95 F at the rear: dated 11/81. The vintage of this helmet's components was similar to Helmet 1. This helmet was tested once in the rear position to supply a base of data to compare to the first helmet tested. This result was used to average test scores for the rear position on the PAC-3 model helmets.

HELMET 5 TEST 33 @ 60"

TEST NO.	LOCATION	SI RESULTS	COMMENTS
33	REAR	788	SAME TURF LOCATION AS TEST 32

At the completion of this testing a new position on the turf was used to conduct bare head form drops from 48 inches. This was done in an effort to show the effect of soil compression on SI readings.

BARE HEAD FORM DROPS FROM 48"

TEST NO.	LOCATION	SI RESULTS	COMMENTS
34	REAR	682	
35	REAR	877	SIGN OF SOIL COMPRESSION
36	REAR	898	
37	REAR	962	
38	REAR	971	MORE PRONOUNCED SOIL COMP
39	REAR	1006	
40	REAR	1014	
41	REAR	1025	STOPPED TO LIMIT DENT DEPTH

B. **Helmet/Helmet Testing**

The test set-up allowed for testing the helmets in a helmet to helmet fashion. Some tests caused helmets to be impacted to helmets that were rigidly retained in a fixed

position, one series of impacts was carried out with the impacted helmet mounted on a Sierra Hybrid II neck. This allowed the impacted helmet to move in a "natural" way during and after impacting. In this series of tests the impacted helmet/headform was instrumented. All NOCSAE series impacts were conducted at the specified NOCSAE drop height of 90", approximately 12mph.

All helmets in the following tests were conditioned at 100°F for a minimum of 4 hours prior to testing. Each helmet was returned to the conditioning environment periodically throughout the test schedule to maintain temperature during testing.

NOCSAE series one, tested the PAC-3 helmet in motion impacting the Air Power helmet. The Air Power helmet was mounted on the un-instrumented NOCSAE headform. The helmets were aligned to cause impact of the upper left front area on the PAC-3 (marked with an "X") against the middle front of the Air Power. Care was taken to prevent any faceguard involvement in the initial impact.

Results series one:

Test Number	SI Results	g's	Drop Hgt.
1	156	44	60"
1a	178	49	60"

NOCSAE series two, tested the WD-1 helmet in motion impacting the Air Power helmet. The Air Power helmet was mounted on the un-instrumented NOCSAE headform. The helmets were aligned to cause impact of the upper left front area on the WD-I (marked with an "X") against the middle front of the Air Power. Care was taken to prevent any faceguard involvement in the initial impact.

Results series two:

Test Number	SI Results	g's	Drop Hgt.
2	163	48	60"
2a	162	49	60"

NOCSAE series three, tested the PAC-3 helmet mounted on the instrumented NOCSAE headform, mounted on the Sierra Hybrid II neck, mounted to a 50th cast torso. The PAC-3 was impacted in the area of the upper left front (marked with an "X"). The Air Power helmet was mounted on the instrumented NOCSAE headform on the drop rig and was positioned so as to strike the PAC-3 with the middle front. Care was taken to prevent any faceguard involvement in the initial impact.

Results series three:

Test Number	SI Results	g's	Drop Hgt.
1 Air Power (analyzer=a)	77	44	60"
1 PAC-3	15	45	60"

NOTE: The similarity in g results indicated the impact was "CG-CG".

ASTM series one tested the PAC-3 helmet in motion, fitted to an instrumented headform (ISO "J"), impacting the Air Power helmet. The Air Power helmet was mounted on the un-instrumented "DOT" headform. The helmets were aligned to cause impact of the upper left front area on the PAC-3 (marked with an "X") against the middle front of the Air Power. Care was taken to prevent any faceguard involvement in the initial impact.

Results series one (ASTM):

Test Number	SI Results	g's	Velocity (m/s)
1 (12:47)	189	54.3	5.55
1a (12:50)	217.5	68.4	5.54

ASTM series two tested the WD-I helmet in motion, , fitted to an instrumented headform (ISO "J"), impacting the Air Power helmet. The Air Power helmet was mounted on the un-instrumented "DOT" headform. The helmets were aligned to cause impact of the upper left front area on the WD-1 (marked with an "X") against the middle front of the Air Power. Care was taken to prevent any faceguard involvement in the initial impact.

Results series two (ASTM):

Test Number	SI Results	g's	Velocity (m/s)
2 (13:08)	209.1	61.9	5.55
2a (13:11)	215.1	64.3	5.57

CONCLUSIONS

A. Helmet/Turf Testing

The testing showed that the soil is more compliant than the standard NOCSAE anvil. This indicates that the NOCSAE test is conservative when compared with this field of play in the locations impacted. Previous testing has shown that an opposing player's helmet is also more compliant than the NOCSAE anvil. The results also showed that all helmets tested performed well below the NOCSAE limit of 1500. It also demonstrated very little difference between models, manufacturers, or age of helmets tested.

Although each series of helmet impacts were subject to the variabilities of changing soil compression and different soil conditions for each location, the results are close enough to give a very high confidence level that any helmet meeting the NOCSAE standard in laboratory conditions would perform at levels well below the 1500 maximum when impacting a playing surface similar to the one tested.

B. Helmet/Helmet Testing

This testing has shown that major brands/models of football helmets perform remarkably similar in the locations and conditions tested. Helmets of various design and age have little effect on the outcome.

This series of testing demonstrated that when helmets collide with other helmets the energy attenuating effect of the helmets are combined so as to further reduce the forces transmitted to the wearer's head. In one series of impacts, when both helmeted headforms were instrumented, the resulting g's were 44 and 45 respectively. This indicated that when impacts occur "CG to CG" the risk of injury to each player is similar.

This testing was carried out at velocities similar to or somewhat higher than those typically experienced by high school football players. Resulting accelerations, even at these higher velocities, were significantly lower in all tests than those thought to cause serious injury, and were well below the pass/fail criteria of established standards.