CONFLICTS OF CONTEMPORARY MOTORCYCLE HELMET STANDARDS

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ABSTRACT

The FMVSS 218 (DOT) standard applies to all motorcycle helmets for use in the USA; the Snell Memorial Foundation promulgates M85, M90 as optional standards of higher performance. DOT and Snell standards have contradicting requirements which affect compliance with the DOT standard, and affect consumer access and affordability. Thirty-six current helmets were tested to the most critical parts of DOT and Snell M85 standards. Another thirty current helmets were tested on the most commonly encountered impact surfaces, recording test performance and structural characteristics. There is deviation from compliance with the DOT standard by a large number of helmets, and significant deviation from compliance by helmets supposedly qualified to Snell standards. The competing requirements cause high-energy Snell helmets to fail DOT dwell time limits, which relates questionable advantage for the most typical accident impacts. At high energy single impacts, DOT helmets perform as well as Snell qualified helmets.

IN 1974 THE UNITED STATES Department of Transportation (DOT), National Highway Traffic Safety Administration introduced Federal Motor Vehicle Safety Standard No. 218 for motorcycle safety helmets. The introduction of this standard includes the following statement, "This standard establishes minimum performance requirements for helmets designed for use by motorcyclists and other motor vehicle users" (FMVSS 218).

The Snell Memorial Foundation has promulgated racing helmet standards since the late 1950's. The foreword of the Snell Motorcycle Helmet Standard, 1985 (M85) states: "The basic premise of the helmet standard is that the circumstances representing the greatest potential hazard will be reproduced under test conditions." (Snell M85).

A series of laboratory tests was designed to determine if conflict would exist between design characteristics which would satisfy "minimum performance requirements" (DOT) and "greatest potential hazard" (M85). In addition, the experimental design includes tests on another group of helmets to determine any difference in performance in simulated accident impacts.

It is expected that DOT qualification does not insure Snell qualification, but the tests reported here show that qualification to Snell does not guarantee that the helmet will pass DOT requirements. All testing was performed at the Head Protection Research Laboratory at the University of Southern California.

Helmet performance requirements: first promulgated in 1974, the DOT standard was revised in 1979 to include most adult helmet sizes on the medium size headform, and most recently in 1988 specifying additional headform sizes (FMVSS 218). DOT and Snell M85 requirements for impact attenuation are summarized in Table 1: the dwell time limits the duration of an impact exceeding the specified levels of 150 and 200g. Snell specifies impact energy rather than a minimum impact velocity. The drop heights listed here correspond to the specified energy or impact velocity using an 11.0 pound ANSI "C" test headform assembly on the monorail or twin-wire apparatus, whichever was appropriate to the standard.

Table 1
Impact Attenuation Performance Summary

	DROP HEIGHT (Ft) Flat Anvil No.1	No.2	DROP HEIGHT (Ft) Hemi Anvil No.1	No.2	PEAK g	DWELL TIME @150g	DWELL TIME @ 200 g
M85	10.0	7.4	10.0	6.7	314*	No limit	No limit
DOT	6.2	6.2	4.7	4.7	400	4.0 msec.	2.0 msec.

*arithmetic average of 285g, no single impact over 314g

TEST METHODOLOGY

Two groups of helmets were tested at the conditions most likely to produce failure. Group I (N=24) consisted of helmets that were labeled as meeting both FMVSS 218 and Snell M1985, and this is noted by "Group I, DOT/SNELL." Two helmets of each model were acquired through motorcycle accessory distributors. The second group (N=12) was labeled as meeting DOT requirements only, and this is noted by "Group II, DOT-Only." A third group of helmets was tested which consisted of fifteen DOT/SNELL labeled helmets and fifteen DOT-Only helmets (Group III, DOT/SNELL and Group III, DOT-Only). These helmets were tested to replicate typical motorcycle accident conditions as determined by accident research.

When the helmets were received the following information was recorded: manufacturer, model, coverage, date of manufacture, size, color, weight and serial number. Each helmet was assigned a four-digit identification number preceded by one or two letters. The letters were assigned at random, each letter denoting helmets of the same make, model and size.

FMVSS Test Procedure 218 specifies that a helmet be positioned on the test headform using a helmet positioning index (HPI) provided by the manufacturer (TP-218-02, 1984). In addition, standardized test headform positions were selected to eliminate variability between tests. As required by FMVSS 218 (S7.1.6), a monorail test apparatus was used for all DOT tests. This monorail apparatus is instrumented with an Endevco 2215E accelerometer and a Savage Digital Signal Processing Unit which measures dwell time to .00001 second. The impact response curves were recorded by a Hewlett Packard X-Y Plotter.

All Snell tests were performed on a twin guide-wire test apparatus, as used by the Snell Memorial Foundation laboratories. This test apparatus is also instrumented with an Endevco 2215E accelerometer and is recorded on a Tektronix 5111 storage oscilloscope.

TEST CONDITIONS - Historically, impact attenuation tests have shown that certain combinations of impact site, test anvil and environmental condition are critical and most likely to produce failure. These critical test conditions were selected for the first two groups of helmets. In the Group I, DOT/SNELL group, the two test helmets of each model were impact tested identically to provide duplication of each critical test. For DOT impacts, the tests were: flat anvil at side and rear, low temperature (-10°C). For M85 impacts, the tests used were: hemispherical anvil at brow and side, high temperature (49°C).

The tests on Group III (N=30) would be expected to have a more direct relationship to the actual performance of helmets involved in accidents. The six-foot drop height corresponds to the 90th percentile impact threat, as determined by accident research (Hurt et al, 1981). The ten-foot drop height used for the remainder of the tests is significant for two reasons; first, it is the same as the first impact required by Snell and, secondly, it represents approximately the 99th percentile impact threat, i.e., generally less than one percent of accident impacts are at this high level of energy. All of these flat anvil tests were done at ambient temperature at the following locations and drop heights: right brow and left rear, ten feet; left brow and right rear, six feet. It is important to note that in spite of the dramatic differences in test requirements and laboratory performance, there has never been any significant difference found in the accident performance of helmets qualified to either DOT or Snell (Hurt et al, 1981).

All impact sites were within the test area as specified by the appropriate standard. The extent of protection specified by M85 extends to the edge of the brow of the helmet, whereas DOT specifically excludes the one inch (25mm) above the reference plane, closest to the brow edge. Because the impact attenuation capability of a helmet is reduced when impacts are located adjacent to an edge of the helmet, all front hemispherical anvil impacts were located 50mm above the edge of the helmet brow (Thom, 1987). This location is generously within the impact boundary specified in M85 and represents a moderate interpretation of the standard. It is certain that most of the test helmets would have failed the critical front hemispherical anvil test had the impact site been located closer to the edge of the helmet, as could be readily interpreted from M85.

TEST RESULTS

DOT AND SNELL LABELED HELMETS - Of the twenty-four helmets tested in Group I, (12 models, 2 each), fourteen failed at least one DOT requirement and ten failed at least one Snell requirement. Five samples failed to meet these critical tests of both standards. The test results for this group of helmets are shown in Table 2.

Peak Acceleration Failures - In the fourteen cases of DOT failure there were no failures of peak acceleration or dwell time limit at the 150g level. All failures were due to excessive dwell time at the 200g level. Since Snell has no dwell time requirements, all failures on Snell were due to excessive peak acceleration, with some helmets completely bottomed out, allowing extreme accelerations, some beyond the test equipment's range of 700g. When a test helmet bottomed out in the first impact, allowing very high acceleration, the second impact at that site was not performed due to the probability of damaging the test apparatus.

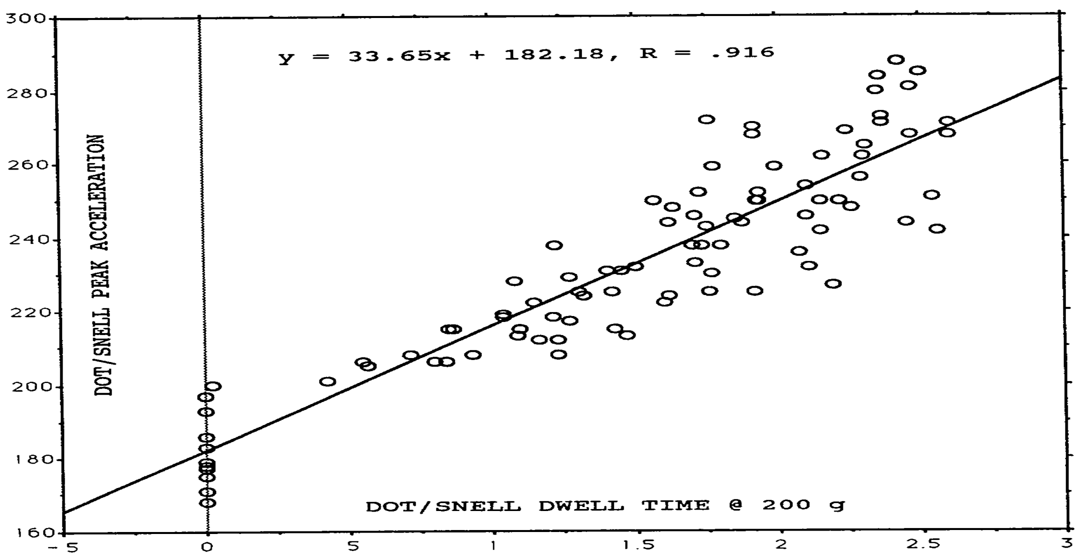

FIGURE 1
Peak Acceleration versus Dwell time @ 200 g
All DOT Impacts of Group I, DOT/Snell Helmets
N (Helmets) = 24, N (Impacts) = 96

DOT Dwell Time Failures - There were a total of twenty-seven failures of the ninety-six DOT impact tests of the Group I, DOT/SNELL helmets (33.8%). Since all DOT failures were of the dwell time requirement, regression analysis was performed on the factors of acceleration versus dwell time at the 200g level. Pearson's R correlation coefficient was 0.916, showing a very strong positive relationship between the two variables.

Table 2

Test Data; Group I, DOT/Snell Labeled Helmets

ID NO.	DOT LEFT FLAT #1 PEAK G	TIME @ 150	TIME @ 200	DOT LEFT FLAT #2 PEAK G	TIME @ 150	TIME @ 200	DOT REAR FLAT #1 PEAK G	TIME @ 150	TIME @ 200	DOT REAR FLAT #2 PEAK G	TIME @ 150	TIME @ 200	SNELL M85 HEMISPHERICAL FRT #1	FRT #2	RT #1	RT #2	DENSITY
A 6540	248	3.16	1.64	259	3.10	1.78	250	3.08	2.22	285	3.07	2.50	170	345	165	160	2.54
A 6545	250	3.37	1.94	272	3.08	1.76	244	3.11	2.45	281	2.99	2.47	160	260	180	160	2.59
B 9905	206	3.45	0.84	231	3.41	1.40	251	3.19	2.54	268	2.99	2.47	190	200	160	160	2.56
B 9913	215	3.42	0.86	225	3.39	1.42	248	3.16	2.26	265	3.01	2.31	180	185	140	145	2.61
C 7246	246	3.27	1.71	268	3.25	1.92	217	3.21	1.27	262	3.24	2.30	190	230	145	150	2.60
C 7248	224	3.25	1.32	250	3.29	1.93	201	3.29	0.42	236	3.21	2.08	195	550	160	140	2.80
D 2717	215	3.43	0.85	228	3.36	1.08	218	3.17	1.21	238	3.14	1.80	190	180	200	175	2.77
D 2719	206	3.25	0.80	238	3.16	1.22	225	3.22	1.76	252	2.81	1.73	195	205	210	185	2.64
E 6392	193	2.67	0.00	218	3.19	1.04	219	2.88	1.04	243	2.84	1.75	298	545	195	205	2.77
E 6394	186	3.04	0.00	197	3.13	0.00	208	3.21	0.71	231	2.68	1.45	245	700	165	120	2.42
F 4756	229	3.38	1.27	250	3.37	1.57	222	3.16	1.15	233	2.76	1.71	160	175	155	160	2.17
F 7388	225	3.34	1.30	246	3.30	2.10	215	2.86	1.10	245	3.26	1.85	165	160	175	155	2.23
G 9176	178	3.74	0.00	205	3.38	0.56	208	3.44	1.23	225	3.63	1.92	160	175	125+	295	2.17
G 9178	206	3.82	0.55	227	3.61	2.19	213	3.57	1.47	232	3.57	2.11	170	310	160	155	2.49
H 7093	222	3.13	1.60	250	2.99	2.15	244	2.78	1.62	270	2.95	1.92	400	665	155	190	2.75
H 7095	212	2.70	1.23	244	2.69	1.88	224	2.89	1.62	259	2.89	1.99	325	495	165	165	2.50
I 6071	242	3.02	2.15	280	3.02	2.35	230	2.95	1.77	273	2.93	2.37	205	245	230	195	3.79
I 6129	271	3.15	2.37	288	3.04	2.43	252	2.97	1.94	284	2.98	2.36	275	700	200	220	3.89
J 5370	175	3.06	0.00	186	2.94	0.00	186	2.68	0.00	208	3.00	0.93	195	535	155	140	2.44
J 5299	171	3.05	0.00	177	2.52	0.00	183	2.62	0.00	212	2.95	1.16	175	215	160	140	2.36
K 9180	168	2.87	0.00	183	3.28	0.00	179	3.13	0.00	200	3.47	0.02	700	*	590	*	1.98
K 5437	242	3.29	2.56	268	3.17	2.60	256	3.04	2.29	271	2.98	2.60	235	240	155	135	4.88
L 1167	213	2.86	1.09	238	2.78	1.70	215	3.11	1.43	254	2.96	2.10	175	230	155	140	2.63
L 1558	238	2.88	1.74	262	2.94	2.16	232	3.12	1.50	269	3.21	2.24	220	225	160	135	2.68

* SECOND IMPACT TEST NOT PERFORMED DUE TO FAILURE ON FIRST IMPACT

+ IMPACT ORDER REVERSED, IMPROPER TEST

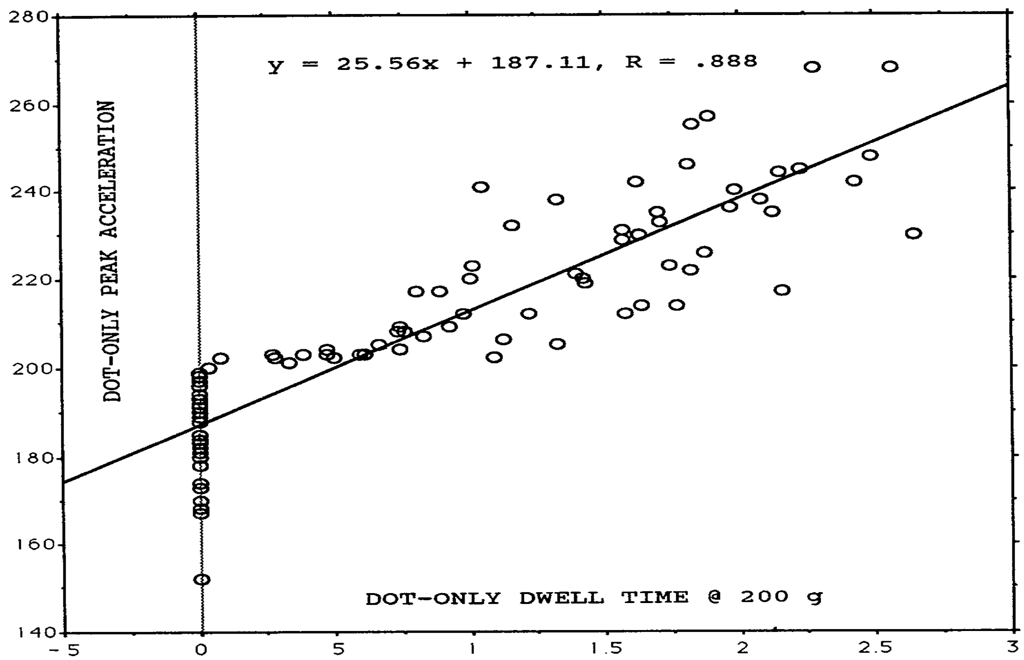

Figure 2
Peak Acceleration versus Dwell Time @ 200g
All DOT Impacts of Group II, DOT-Only Helmets
N (Helmets) = 12, N (Impacts) = 96

Linear regression predicted peak acceleration for a 2.0 msec. dwell time of 253g. Ninety-five percent confidence bounds for this value are +31g, giving a statistically-predicted maximum peak acceleration of 284g associated with a 2.0 msec. dwell time above 200g. The same prediction for 1.8 msec. (90% of specified limit) equals 247g. This relationship shows that in the region of 250g, small differences in acceleration can mean the difference between passing and failing of the dwell time limitation. While it has been argued that the 400g peak acceleration limit is too high, these tests show that meeting the dwell time limits of the DOT standard has the effect of reducing peak acceleration far below the 400g otherwise allowed (Federal Register, 1988). It should be noted that the highest acceleration associated with a passing 200g dwell time in these tests was 277g, slightly lower than statistically predicted. Figures 1 and 2 show plots of these variables for these two groups of helmets.

DOT-ONLY LABELED HELMETS (Group II) - Since this group of helmets was labeled as meeting only the DOT standard, no tests were done to the requirements of M85. Prior testing has shown that most of these helmets would not pass the high-energy 10 foot drop onto the hemispherical anvil.

There were no failures of peak acceleration in Group II. Out of ninety-six test impacts on the twelve helmets, there were no failures of the 150g dwell time limit but 10 failures (10.4%) of the 200g dwell time limit of 2.0 msec. One helmet accounted for three of these failures, with seven of the helmets having no failures at all. The test results for this group are shown in Table 3.

Table 3
Test Data; Group II, DOT-Only Helmets

ID NO.	FRONT FLAT #1 PEAK g	TIME @ 150	TIME @ 200	FRONT FLAT #2 PEAK g	TIME @ 150	TIME @ 200	LEFT FLAT #1 PEAK g	TIME @ 150	TIME @ 200	LEFT FLAT #2 PEAK g	TIME @ 150	TIME @ 200
M 1527	180	2.68	0.00	199	3.06	0.00	197	2.99	0.00	212	3.13	1.22
N 2610	189	2.45	0.00	236	3.00	1.97	203	3.24	0.27	268	3.20	2.57
O 8128	178	2.70	0.00	214	3.11	1.77	173	2.18	0.00	203	2.87	0.47
P 3721	168	2.32	0.00	233	2.97	1.71	174	2.37	0.00	188	2.43	0.00
S 0127	185	2.63	0.00	238	3.17	2.08	220	3.57	1.42	244	3.42	2.15
T 5049	202	2.98	0.08	245	3.28	2.23	196	3.32	0.00	212	2.64	0.98
U 3384	152	0.82	0.00	180	2.90	0.00	180	3.18	0.00	204	2.83	0.74
V 9494	190	3.05	0.00	202	3.10	1.09	229	3.30	1.57	255	2.91	1.83
W 1055	199	2.53	0.00	235	2.95	1.70	194	2.78	0.00	199	2.69	0.00
X 1067	205	3.17	1.32	219	3.13	1.43	203	3.47	0.61	209	2.51	0.92
Y 1027	170	2.28	0.00	231	2.80	1.57	191	3.39	0.00	212	3.43	1.58
Z 9313	203	2.91	0.27	240	3.15	1.98	203	2.17	0.59	248	3.11	2.49

CONTINUED

ID NO.	RIGHT FLAT #1 PEAK g	TIME @ 150	TIME @ 200	RIGHT FLAT #2 PEAK g	TIME @ 150	TIME @ 200	REAR FLAT #1 PEAK g	TIME @ 150	TIME @ 200	REAR FLAT #2 PEAK g	TIME @ 150	TIME @ 200	DEN-SITY
M 1527	200	3.04	0.04	222	3.27	1.82	181	2.30	0.00	209	3.62	0.74	2.51
N 2610	206	3.16	1.12	235	3.16	2.12	203	3.44	0.39	232	3.69	1.16	2.83
O 8128	192	2.96	0.00	230	3.25	1.63	198	3.53	0.00	223	3.53	1.01	2.06
P 3721	167	2.58	0.00	183	3.01	0.00	193	3.46	0.00	220	3.60	1.60	2.34
S 0127	223	2.86	1.74	238	2.66	1.32	205	2.62	0.66	246	3.19	1.81	2.12
T 5049	182	2.90	0.00	204	3.14	0.47	193	2.38	0.00	217	3.05	0.89	2.41
U 3384	182	3.30	0.00	208	3.24	0.76	202	3.08	0.28	226	3.22	1.87	2.46
V 9494	221	3.15	1.39	257	2.87	1.89	217	3.48	2.16	242	3.47	2.43	2.69
W 1055	197	3.02	0.00	202	2.83	0.50	183	3.00	0.00	217	2.43	0.80	2.88
X 1067	201	3.48	0.33	241	2.53	1.05	190	2.92	0.00	242	2.97	1.62	3.02
Y 1027	168	2.44	0.00	184	2.34	0.00	182	2.31	0.00	207	2.53	0.83	2.17
Z 9313	214	2.81	1.64	268	3.01	2.68	208	3.72	0.73	230	3.96	2.64	3.38

In all cases, the mean values of peak accelerations for the Group II, DOT-Only helmets were significantly below those of the Group I, DOT/SNELL helmets. For the first impact, the means were 194 (sd=16.3) versus 219 (sd=24.9), with a difference of 25g (t=5.74, P=.0004). For the second impacts, the results were 223g (sd=21.5) versus 244g (sd=28.2), with a difference of 21g (t=4.199, P=.00005). The overall DOT test impacts for each group were 208g (sd=24.1) versus 231g (sd=29.2), a statistically significant difference of 23g (t=6.99, P=.0004).

The mean values of dwell time at the 200g level were also significantly different. While there were a total of twenty-seven dwell time failures in the Group I, DOT/SNELL group, there were only ten in the Group II, DOT-Only group. Also important to note is that only one of the excessive dwell times in the Group II, DOT-Only group was on the first impact, compared to eight in the DOT-SNELL group. This is particularly important because on-scene accident research has shown that second impacts occur only rarely (6.3%) and always at a lower level of energy (Hurt, et al, 1981)

As with the first group, correlation was analyzed for the factors of peak acceleration versus dwell time at 200g, seen in Figure 2. The correlation coefficient was 0.888, again showing a strong correlation between these variables.

AMBIENT FLAT ANVIL TESTS (GROUP III) - The DOT-Only group (N=15) showed statistically significant (t=5.659, P=.0001) lower accelerations on the six-foot tests with an average of 189g (sd=21.7) compared to 210g (sd=28.3) for the DOT/SNELL group (N=15). These results are shown in Table 4 and the results for the DOT/SNELL group in Table 5. It might be expected that the Group III, DOT-Only helmets would be overwhelmed when subjected to the more severe ten-foot impact test since they are not designed to withstand that level of energy. These tests show no significant difference (t=0.7, P=.2449). The DOT-Only group averaged 253.7g (sd=24.2) compared to 250.9g (sd=26.7) for the Group III, DOT/SNELL group.

Table 4
Group III, DOT-ONLY Qualified Helmets, Flat Anvil, Ambient Condition Tests

ID		R.BR. 10 FT	L.R. 10 FT	R.R. 6 FT	L.BR. 6 FT	DENS. LB/CU.FT	THK. IN.
AA	3903	240	255	190	170	2.75	1.2
BB	8712	300	250	190	150	2.70	1.0
CC	4313	260	310	250	195	4.18	1.1
DD	9289	240	275	210	170	3.56	1.3
EE	6269	230	285	215	155	3.78	1.4
FF	2465	225	270	195	165	3.40	1.3
GG	4700	240	275	195	160	3.76	1.4
HH	4619	225	240	170	145	2.68	1.2
II	5758	230	260	195	155	2.99	1.2
JJ	2361	240	250	190	135	3.17	1.3
KK	0510	225	250	195	145	3.61	1.4
LL	7332	210	275	205	145	3.59	1.4
MM	2813	240	290	215	170	3.52	1.2
NN	6672	240	275	210	180	3.88	1.3
AG	2401	265	240	205	165	3.59	1.3

Energy-absorbing Liner Density - While helmet performance is influenced by complex interaction between the shell and the energy absorbing liner, there is an important correlation between liner density and helmet performance. All liners were expanded polystyrene bead foam (EPS). When all testing was completed, the helmets were disassembled and the density of each liner was determined by weighing and fluid displacement. The densities were corrected to approximate pre-test values by multiplying the post-test density by 0.95. Most densities measured were in the two-to-three pound-per-cubic-foot range. There were three exceptions and two of these were samples of the same model. These two exceptions powerfully illustrated the conflicting requirements of the two standards. Helmet K9180 had a very soft, low density liner (1.98 lb/cu.ft.) and passed DOT requirements easily with all peak accelerations at 200g or less. K5437 had an extremely hard liner (4.88 lb/cu.ft.) with peak accelerations ranging from 242 to 271g and failed the dwell time requirement on all four DOT test impacts but easily passed those of Snell, as shown in Table 6.

Table 5
Group III, DOT-SNELL Qualified Helmets, Flat Anvil, Ambient Condition Tests

ID		R.BR. 10 FT	L.R. 10 FT	R.R. 6 FT	L.BR. 6 FT	DENS. LB/CU.FT	THK IN.
OO	2146	230	255	200	160	2.50	1.3
PP	1848	245	285	215	185	2.78	1.3
QQ	0913	255	280	205	185	3.81	1.3
RR	9275	270	325	265	195	2.96	1.2
SS	1900	215	240	165	170	3.24	1.3
TT	1879	225	225	175	160	2.75	1.3
UU	1689	250	275	245	195	2.91	1.4
VV	2926	250	260	220	200	2.32	1.3
WW	5005	245	260	205	195	2.39	1.3
XX	7154	255	245	190	190	2.54	1.2
YY	4458	200	255	195	145	3.26	1.3
ZZ	0501	260	275	200	210	2.12	1.4
YY	4459	195	245	190	140	3.18	1.3
AC	6451	200	275	220	180	3.38	1.3
AD	2885	245	280	225	220	2.65	1.2
AE	1440	220	280	210	170	3.13	1.3
AF	4655	255	295	245	225	2.94	1.3

The soft, low-density liner in K9180 that so easily passed all DOT tests was immediately overwhelmed by the first M85 hemispherical impact allowing extreme accelerations.

Table 6

HELMET	LINER DEN. (lb/cu.ft.)	DOT DWELL TIME @ 200g	SNELL PEAK g
K9180	1.98	0, 0, 0, 0.02	>700, * 590, *
K5437	4.88	2.56, 2.60, 2.29, 2.60	235,240 255,135

(* second impact not done due to failure on first)

Of the Group I, DOT/SNELL helmets, the most dense liner to pass all tests was 2.77 lb/cu.ft. (D2717) and the lowest was 2.17 lb/cu.ft. (G9176). The highest density liner to pass all DOT impacts was 2.77 lb/cu.ft. (D2717) with a subgroup (N=10) mean of 2.47 lb/cu.ft. (sd=.23). Of the larger subgroup (N=14) that failed at least one DOT test, the mean liner density was 2.93 lb/cu.ft. (sd=.73). This is 18.6% higher than the passing group. It is also noteworthy that the helmet with the lowest density liner (K9180) had the lowest maximum acceleration on DOT tests, barely reaching 200g with a dwell time of 0.02 msec. at that level. The other three impacts to this helmet measured no dwell time at 200g since peak accelerations were less than 200g.

Among the Group II, DOT-Only helmets, the liner densities ranged from 2.17 to 3.49 lb/cu.ft. The ambient, flat anvil DOT-Only helmets measured somewhat higher with a range of 2.68 to 3.88 lb/cu.ft. (helmet CC4313 had an unusually dense 4.18 lb/cu.ft. liner and performed poorly in all tests). The mean densities for passing and failing helmets were nearly identical, 2.57 versus 2.53 lb/cu.ft. respectively. For all DOT-Only helmets (N=29), the average density was 3.16 (sd=.529) and the Group I, DOT/SNELL helmets (N=37) overall average 2.80(sd=.563). This difference is barely significant (t=2.721, P=.0122). This confirms the interaction between the shell and liner and the extremely stiff shell required to withstand the M85 hemispherical impacts.

Energy-absorbing Liner Thickness - After testing, the thickness of the energy-absorbing liners were measured at unimpacted areas within the test region. The liners ranged from 1.2 to 1.5 in. in thickness with a mean of 1.35. Of the five helmets in the first two groups that passed all tests, none had a liner thickness less than 1.3 in. Comparison of the Group II, DOT-Only and Group I, DOT/SNELL shows little average difference in thickness between the two groups, 1.27 (sd=.118) versus 1.29 (sd=.056) in. This difference is not significant (t=.845, P=.2062).

Helmet Shells - The shells of the DOT/SNELL groups were predominately composite construction, usually fiberglass-reinforced polyester resin. Some were reinforced with Kevlar. The shells of the DOT-Only group were mainly injection-molded thermoplastic, e.g. polycarbonate. The shell materials are shown in Table 7. The function of the shell is to distribute the impact energy over a wide area of energy-absorbing liner. The shell stiffness prevents excessive localized damage that could result in the helmet liner bottoming out, indicating that its energy-absorbing capability is exhausted. Because of this function, the strength and stiffness of the shell is most critical for hemispherical anvil tests. For flat anvil tests, the load-spreading function of the shell can actually result in increased acceleration because the impact is spread out over such a large area of liner that the liner cannot yield sufficiently. Because of this conflict, the helmet manufacturer cannot simply make a shell extremely strong to survive hemispherical anvil impacts, then expect it to pass flat anvil impact tests. A properly-designed shell must be strong enough to resist the concentrated impact of a hemispherical anvil yet flexible enough to allow the liner to be crushed in flat anvil tests. The shell strength and liner density are not separate functions, but interact to successfully complete the impact attenuation tests, then provide protection for the wearer.

There were two shell fractures encountered during this testing. Helmet T5049 (Group II, DOT-Only; polycarbonate shell) fractured on the second DOT impact on the left side. The fracturing was localized and had no effect on subsequent impacts at other sites. The result of the second impact during which the fracture occurred was only 212g, which is a typical result since fracturing the shell adds energy absorption, given that the fracture does not occur prematurely. The other fracture was on helmet BB8712 at the right brow (10 foot) impact site. The fracture was 2.5 in, long on this Antracol(ABS alloy) shell. The peak acceleration was an above average 300g and it is important to note that this helmet had the thinnest liner of all helmets tested, 1.0 in.

Table 7
Helmet Shell Materials

Fiberglass reinforced polyester resin:
A 6540, A 6545, B 9905, B 9913, C 7246, C 7248, D 2717, D 2719, F 4756, F 7388, G 9176, G 9178, H 7093, H 7095, I 6071, I 6129, L 1167, L 1558, S 0127, V 9494, OO2146, PP1848, SS1900, UU1689, WW5005, XX7154, AD2885, ZZ0501

Fiberglass & Kevlar reinforced polyester resin:
E 6392, E 6394, J 5370, J 5299, AC6451, AE1440, AF4655, RR9275, TT1879

Polycarbonate, Injection molded:
T 5049, U 3384, X 1067, DD9289, EE6269, FF2465, GG4700, HH4619, YY4459, JJ2361, KK0510, LL7332, MM2813, NN6672, AG2401, QQ0913, YY4458

Ronfalin, Injection molded:
N 2610, O 8128, P 3721, W 1055, Y 1027, BB8712, CC4313

Unspecified thermoplastic: Z 9313, II5758, AA3903

Polyester, Injection molded: K 9180, K 5437

Antracol, Injection molded: M 1527

DISCUSSION

The comparison tests of this paper indicate that helmets qualified only to DOT are simply more successful in actually qualifying to the DOT standard, and the helmets qualified to the Snell standard have significantly greater faults in DOT testing. The tests on Group III also show that there is no advantage inherent in Snell certification in flat surface impacts. The side-by-side comparison of helmet tests to both DOT and Snell standards suggests a true conflict between these standards, and surely this establishes an undesirable competition between them. The critical DOT dwell time limits require a relatively soft, low-density liner and more flexible shell which generally cannot satisfy the high energy Snell impacts with contemporary liner thickness. On the other hand, the harder, high-density liner and extremely stiff shell suitable for Snell impacts produces excessive responses on the DOT impact tests.

Motorcycle collision research at the University of Southern California showed that riders most often strike their heads on flat surfaces, usually the roadway. Analysis of the damage to accident-involved safety helmets showed that the six-foot drop height of FMVSS 218 corresponds to the 90th percentile impact in the 355 helmets worn in 900 motorcycle accidents (Hurt et al, 1981). These research data indicate that impact protection at the six-foot drop height required by DOT is the typical requirement in the vast majority of traffic accidents. Since the DOT standard requires two impacts to the same site, the factor of safety is actually quite high. These same on-scene, in-depth accident data do not show that helmet standard qualification affects accident performance and head protection in motorcycle accidents.

The statistical analysis proves that there is a significant conflict and competition so that qualification to the Snell standard is detrimental to DOT qualification. Further, the competition obviously extends to the marketplace where, although no premium of protection has been found in any research, a "racing standard" qualification is very helpful in justifying a $200 to $400 price for a premium helmet.

The following recommendations should provide a solution to the conflict:

1. Snell standards should not be in conflict or competition with FMVSS 218, and should incorporate DOT requirements within the Snell standard,

2. Snell standards should be revised to a bona fide higher level of performance by the significant reduction of acceleration limits, i.e., a reduction of allowable acceleration to the range of 150 to 200g rather than simply increasing the test impact energy with each revision of the standard.

3. Snell standards should be enforced more diligently; the compliance failure rate is significant.

In this way, the qualification of a helmet to both DOT and Snell would have real meaning to the motorcyclist with the DOT providing the minimum qualification and the Snell qualification providing a bona fide higher level of protection performance.

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