EVALUATION OF THE DYNAMIC TEST REQUIREMENTS FOR CHILD RESTRAINTS ACCORDING TO THE ECE 44 REGULATION

by

J.C. Bastiaanse, J. Maltha and A.G.M. Tak
Research Institute for Road Vehicles TNO, Delft, The Netherlands

ABSTRACT

An evaluation of the dynamic test requirements of the ECE 44 child-restraint regulation is made, based on a 1½ years of experience with a wide variety of child-restraint systems in about 450 tests. The performance of current "state of the art" child-restraint concepts is discussed, the conclusion being that most current designs need substantial modifications to fulfil the ECE 44 requirements.
There is a problem with the seats using adult 3-point belts as regards the chest acceleration tolerances. The padded shield-type seats with lap belts, on the other hand, have a tendency to exceed the maximum head excursion limit of 550 mm. Most systems using belts show abdominal penetration, often resulting in a submarining. The regulation is found to be very restrictive, which could lead to overcomplicated systems likely to be rejected by parents. A cause of the difficulty can be the seat cushion of the ECE 44 bench seat which seems to be too soft. Some improvements to the dummies and the abdominal penetration measurements is discussed. Measurement of head accelerations is proposed because of the possibility of head contacts with certain types of restraint systems.

INTRODUCTION

The Economic Commission for Europe of the United Nations installed the "Ad hoc Group for Child Restraints" in 1977. The task for this group was to draft "Uniform conditions concerning the approval of restraining devices for child occupants in power-driven vehicles".
From the outset the intention of the Ad hoc Group was to approach the problem afresh from various viewpoints and not to rely heavily on existing rules. Specialists from different disciplines therefore cooperated in examining not only the general safety problem, but also safety-related aspects, such as usability, comfort and rescue. This group produced a draft standard in 1979 which was submitted to Working Party 29 of the ECE in Geneva. The draft, after a number of modificatons, was adopted by the United Nations as ECE Regulation 44 and came into force on 1st February 1981 [1]. Since then the regulation has been adopted in the United Kingdom, the Netherlands, Denmark and Sweden. Many other countries are expected to do so in the near future.
The regulation requires a 50 kmh frontal impact test for evaluation of the safety performance of the systems. The child-restraint systems are tested on a soft bench seat with a deceleration pulse representative of current production cars (Fig. 1).
The regulation specifies a group of four dummies representing mass and anthropometry of children aged nine months, three years, six and ten years [2]. A special requirement for the dummies was a realistic pelvic shape and a soft abdomen suitable for the measurement of abdominal penetration (Fig. 2).

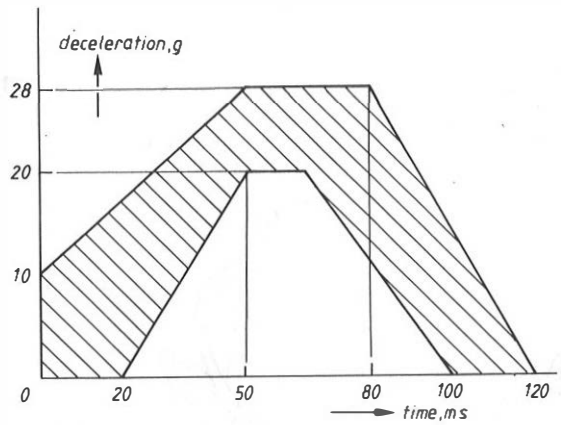


Fig. 1 Tolerance corridor for the sled deceleration curve in ECE 44 dynamic test.

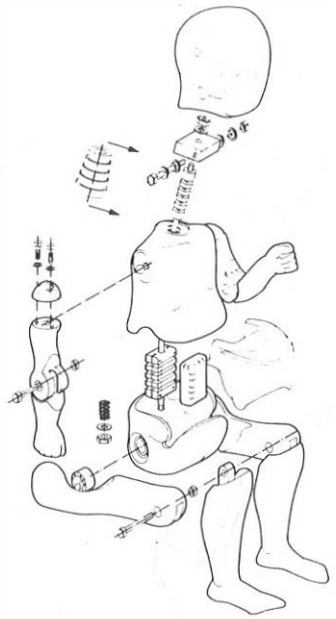


Fig. 2 Exploded view of TNO P-series child dummy.

Requirements of the ECE 44 regulation which are essential for the safety performance are:

- a limit value on the resultant chest acceleration of 50 g except during periods whose sum does not exceed 3 ms;
- a maximum forward head excursion of 550 mm measured from the intersection point of seat-back and seat-cushion planes;
- no essential abdominal penetration allowed.

The regulation specifies no measurements for the head acceleration because it was felt that avoidance of any head contact by limiting the forward head excursion was sufficient protection for the head. Many current child-restraint systems, however, are of the impact-shield-type allowing a head contact. In addition to the above-mentioned parameters in the tests carried out at TNO, head acceleration has been measured to assess the injury-producing potential of the head contact.

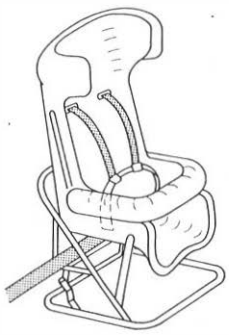
The paper presented here gives an evaluation of the dynamic test procedure and discusses the performance of current "state of the art" child-restraint concepts based on experiences with the regulation at TNO.

TEST PROGRAM

During the last 1½ years the test laboratory of TNO carried out about 450 tests with a wide variety of child-restraint systems. The concepts of these systems ranged from simple adjustment to a 3-point adult belt system to completely integrated seats with harness belts.

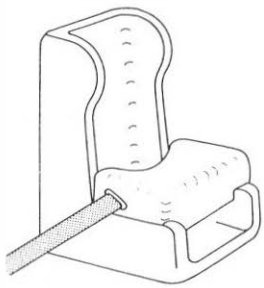
Most of the tests were carried out according to the requirements of the ECE 44 regulation and were done for homologation, for product development and for consumer investigations.

For the present paper, 140 tests on restraint systems have been selected as representative of one of the six main categories that we defined (Fig. 3). These main categories are representative of child-restraint systems as manufactured up to the beginning of 1981.

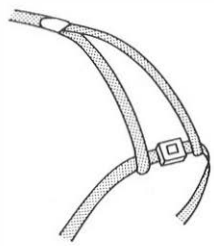


A seats with harness belts

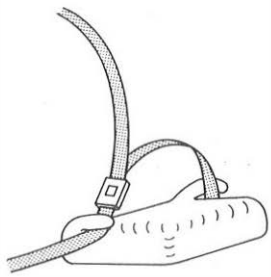
B seats using adult 3-point belts



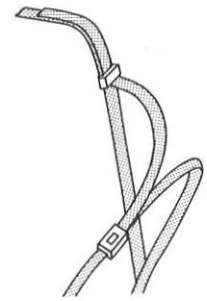
C seats with impact block using lap belts



D harness belt systems only



E booster seats using adult 3-point belts



F adult 3-point belts with guiding straps

Fig. 3 Definitions and examples of six main categories of child-restraint concepts.

All systems that failed a test badly or did not conform with defined categories, and tests deviating too much from the R 44 conditions, were not directly considered for this study. However, the experience gained in the 450 tests is reflected in the discussion.
The number of types and the number of tests for each defined type and age group are presented in Table 1.

Table 1 Summary of number of tests for each restraint category distributed over the age groups

restraint category	tested types	dummy P ¾	dummy P 3	dummy P 6	dummy P 10	total number of tests
A seats with harness belts	5	13	13	5	–	31
B seats using adult 3-point belts	2	3	4	5	–	12
C seats with impact block using lap belts	5	14	18	4	–	36
D harness belt systems only	3	–	5	6	3	14
E booster seats using adult 3-point belts	4	–	8	10	12	30
F adult 3-point belts with guiding straps	2	–	6	7	2	17
Total number of types and tests	21	30	54	37	19	140

TEST RESULTS

In all tests the following injury prediction parameters were measured or calculated. The limit values for those parameters that are part of the ECE 44 requirements are given between brackets.

- resultant head acceleration
- head injury criterion HIC
- resultant chest acceleration (max. 50 g exceeding 3 milliseconds)
- vertical chest acceleration (max. 30 g exceeding 3 milliseconds)
- chest severity index, CSI
- maximum forward head excursion (max. 550 mm)
- abdominal penetration (no penetration allowed).

The complete results of the 140 tests are summarized for each category of restraint in six tables given in the annex. These tables show test results for each particular child restraint and for each of the age groups relevant to the considered product. Most of the tests are repeated 2, 3 or 4 times for the same condition to assess the repeatability. The last row in each table gives the average values for each product.

The maximum forward head excursion is presented in the tables relative to the head excursion limit of 55 cm. For example, +15 means that the head stops 15 cm before the limit of 55 cm, and -15 means that this limit is exceeded by 15 cm. The abdominal penetration is measured with the modelling-clay-imprint technique as proposed in the regulation, backed up by high-speed film analysis.

Table A presents test results for seats with harness belts. These systems differ in principle from the others in requiring a top strap from the child seat to the parcel shelf of the car. The table gives the results for five different products coded A1 ... A5. The first three have a 4-point harness and the last two a 5-point harness, i.e. they have a crotch strap.

Table B presents test results for seats using the adult 3-point belts. Only two products were tested B1 and B2. In the tests with the "6-year-old" dummy on type B1, the lap-belt guide did not function properly, resulting in severe submarining which, in turn, affected all the other measured parameters.

Table C presents test results for seats with an impact block using the adult lap-belts only. Five products, coded C1 ... C5, were tested. For these types of restraints no abdominal penetrations have been detected, as the impact block loads the abdomen and chest over a large area and avoids any essential penetration.

Table D presents test results for special harness-belt systems only. Three products have been tested, coded D1, D2 and D3. All types show an abdominal penetration from the lap strap resulting in significant submarining which, in turn, affects all other measured values, especially the forward head excursion.

Table E presents test results for booster seats using the adult 3-point belts. Four products, coded E1 ... E4, were tested. The last two products E3 and E4 have inadequate lap-belt guidance, resulting in abdominal penetration by the belt and a submarining in all tests. Because of the submarining, the results for the other measured values are not meaningful.

Table F presents test results for adult 3-point belts with guiding straps. Three products were tested and coded F1, F2 and F3. Again, all systems gave an abdominal penetration resulting in significant submarining.

The results presented in these tables are too detailed to base any general conclusions on. For this reason a graphical presentation is given of the two main

requirements of the regulation, head excursion and chest acceleration, for each of the categories of restraints and for each age group test. The graphs directly show whether the type of restraint system meets or fails to meet the requirement for certain age groups. The graphs are based on the average results of all tests for all products in the category considered (Fig. 4).

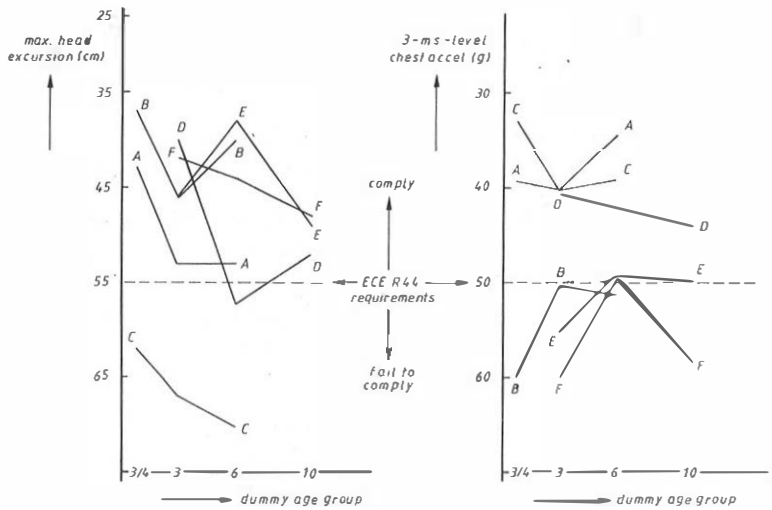


Fig. 4 Averaged head excursion and 3-ms levels of resultant chest acceleration for each restraint category, distributed over the age groups.

Table 2 General conclusions on conformity with Regulation R 44 based on averaged results

restraint systems	Meets the requirements of R 44 with respect to excursion head	acceleration chest	abdominal loading	crotch strap allowed
A seats with harness belts				
- without crotch strap	yes	yes	no	--
- with crotch strap	yes	yes	yes	no
B seats using adult 3pts belts	yes	no	yes	--
C seats with impact-blocks using lapbelts	no	yes	yes	--
D harness belt system only	no	yes	no	--
E booster seats using adult 3pts belts	yes	no	yes	--
F adult 3pts belts with guiding straps	yes	no	no	--

The general conclusion to be drawn from the graphs, that is whether a system meets or fails to meet the requirement for all age groups, is given in Table 2 together with that of meeting the abdominal penetration requirement of the considered restraint category. The table distinguishes between seat-harness systems with and without a crotch strap in category A.

Table 2 clearly shows that, on the average, the current child-restraint concepts have difficulties in meeting the regulation. Since the above conclusion is based on averaging the results for good and bad products, thus obscuring the potential of some systems, we have also selected the best products out of each group. The results of head excursion and chest acceleration of the best products are presented in Fig. 5 and Table 3. The general trend in these graphs shows that there is a tendency towards meeting the requirements better, but the graphs also show that the head-excursion and chest-acceleration requirements are often in conflict and that, together with abdominal loading, generally the regulation requirements are not adequately fulfilled.

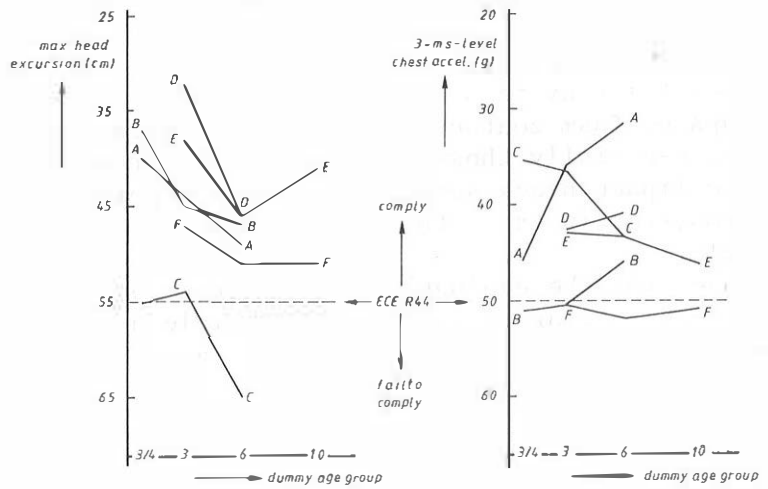


Fig. 5 Head excursion and resultant chest accelerations for the best product in each restraint category.

Table 3 General conclusions on conformity with Regulation R 44 on the part of the best product in each restraint category

restraint systems	Meets the requirements of R 44 with respect to excursion head	acceleration chest	abdominal loading	crotch strap allowed
A seats with harness belts (with crotch strap)	yes	yes	yes	no
B seats using adult 3pts belts	yes	no	yes	--
C seats with impact-blocks using lapbelts	no	yes	yes	--
D harness belt systems only	yes	yes	no	--
E booster seats using adult 3pts belts	yes	yes	yes	--
F adult 3pts belts with guiding straps	yes	no	no	--

DISCUSSION OF TEST RESULTS

Looking at the results generally, considerable differences were observed between the results obtained for the different products in each restraint category. These relate to the different constructions of the systems but are found also in apparently identical products. From this can be concluded that the test results in the ECE 44 regulation are very much influenced by construction details.
Let us look at the tests which were repeated. With a particular system, deviations were observed between the test results which for some types were very large. This problem of repeatability is caused by a variety of factors. First, the test input conditions can differ slightly, the sled velocity and deceleration vary a little, the initial position of the restraint system and the dummy are never exactly the same, the belt pretension and adjustment may differ, belts with automatic retractors activate perhaps at different moments, etc. Second, the tested restraint systems may differ slightly. In addition most of the systems use straps or foam contacts that evince nonrepeatable friction phenomena. Some systems, especially those with symmetrical restraints, such as the harness seats and the impact block seat, show better repeatability than other nonsymmetrical systems, for instance the booster seats combined with an adult 3-point retractor belt.
Finally, the dummy used for the evaluation measurement may give different results for identical inputs owing to the tolerance field arising out of the dummy's calibration condition [3, 4].
The first and third causes of the nonrepeatability can be largely eliminated by carefully controlling the test set-up conditions and the calibration of the dummy. The second cause is inherent in the tested restraint system.
If a restraint system under slightly varying input conditions produces largely different test results we refer to it as a non-stable system. Because of the fact that in real-world accidents the input conditions vary considerably which, in non-stable systems, may lead to inadequate protection, we have our doubts about such systems. We expect that the regulation is more representative of the real-world performance of the more stable systems than it is of non-stable systems.

DISCUSSION OF TEST PROCEDURE

From the test data available, it can be concluded that it is difficult to design a system that meets the requirements of this regulation. Experiences with optimizations on current designs at TNO show that we are dealing basically with two conflicting requirements, that is, the limit in head excursion and in chest acceleration [5, 6]. When the head excursion is kept within limits by restraining the upper torso with straps or foam blocks, we often observe too high a chest acceleration. When the ride-down of the chest is improved with a lower acceleration, the criterion for maximum head excursion is often exceeded. Looking at field accident data for current child restraints, however, there is no strong evidence that the protection afforded is insufficient. For this reason we consider the current requirements to be too restrictive. They force the manufacturers into overcomplicated systems that are neither comfortable nor practical and that could lead to rejection by the parents.
As regards the current ECE 44 regulation it is felt that the following items should be considered for improvement:

ECE test bench seat:
The soft seat prescribed for the regulation test is one of the major causes of excessive forward rotation of those child-restraint systems that use only a

lap belt. The seat-foam softness was based on the results of a 1977 study of seat cushions in private cars, at that time currently on the market. This foam fully extends from the seat surface to the flat bottom of the sled, which allows large penetrations. A pilot study on recent car types, however, shows much more seat hardness due to thinner seat cushions with an underlying sheet-metal seat-pan.
This problem of seat stiffness and construction should be reconsidered.

Dummies:
There are some aspects on the dummy that must be changed. This is the modification of some construction details with the aim of improving the durability and the calibration quality. This modification program has recently been put into effect at TNO.
The main improvements were in the adjustments of the joints and a better design of the spine-neck cable and its attachments. The improvements on the spine-neck cable are expected to result in more repeatable measurements of head accelerations.

Abdomen penetration measurement:
The current regulation defines a measuring method which is based on evaluation of a permanent imprint on a piece of modelling clay. This method is criticized because it shows two deficiencies. The first problem is that the clay does not distinguish very clearly between an imprint from a belt and an imprint from the dummy sternum itself during much forward bending. Therefore it is not a very objective measurement and it requires some experience on the part of the test engineer. The second problem is that in very severe submarining in which there is belt penetration high under the lower ribs, there is no indication at all. Practice at TNO is to base the evaluation not only on the clay imprint, but also on analysis of high-speed film of the test, a procedure also in use in other laboratories.
Currently some alternative methods are being studied, one of which, a method with an imprint on so-called "bubble-foil" developed in the United Kingdom, shows good promise.

Head acceleration measurement:
The current regulation does not require head acceleration measurement. The reasoning behind this was that it was felt to be sufficient to avoid any head contact with the vehicle interior by limiting the forward and vertical head excursion. Since the start of the work of the ad hoc group however, some restraint systems have evolved towards systems with foam-impact blocks or shields. In these systems head contacts with the block or shield often occur. For this reason TNO feels that some restriction should be placed on the severity of this head contact by setting a limit to the resultant acceleration. From recent experiences with designs using respectively soft and rather hard foam in the impact block, we think a reasonable limit would be a maximum of $\sim$ 80 g for the resultant head acceleration at durations exceeding 3 milliseconds. Another more complicated method could be to put some limit value to the HIC calculated during contact only.

SUMMARY AND CONCLUSIONS

TNO carried out some 450 dynamic tests on a wide variety of child-restraint systems according to the requirements of the recently adopted ECE 44 regulation. This study presents an evaluation of the performance of current child-restraint concepts and evaluates the ECE test requirements. For this study 6 main groups representing the different child-restraint concepts were defined and, on this

base, the 140 most representative tests were selected for more detailed analysis. From this analysis we could conclude that all current child-restraint concepts have difficulties in meeting the requirements. They all fail for various reasons. Some systems fail by exceeding the head excursion although they show an acceptable chest acceleration. Other systems fail by exceeding the chest acceleration limit and the head excursion is well within the set limits. Many systems restraining the child with belts directly on the body fail because the abdomen-penetration criterion is not met.
These findings do not mean that the dynamic performance of the various categories is not feasable for improvements and might eventual meet the requirement of R 44. But, based on the fact that field accident data put forward no strong evidence of inadequate protection, the question should be put forward whether or not the current requirements are too restrictive and for that reason conducive to the emergence of overcomplicated systems that might well be rejected by the parents.
One reason for the too restrictive requirements in the regulation can be the very soft test seat, causing excessive forward rotation of some restraint concepts.
Improvements on the dummy construction increasing the calibration condition are discussed. Problems encountered with the modelling clay technique for abdominal penetration measurement are discussed briefly.
The current ECE 44 regulation requires no head acceleration measurement, but since some restraint concepts allow a severe contact between the dummy head and an impact block or shield we think that such measurement should be reconsidered. A maximum resultant head acceleration value of $\sim$ 80 g exceeding 3 milliseconds has been proposed.
Summarizing, the following conclusions have been arrived at:
- most current restraint systems have difficulties in meeting the ECE 44 requirements;
- the requirements are too restrictive and may lead to overcomplicated designs;
- a reason for over-restrictive requirements could be the excessive softness of the test seat, the performance of this seat should be reconsidered;
- the dummy construction needs some detail improvements;
- the measurement of head accelerations in the case of a head contact with the restraint system is proposed.

REFERENCES

1. ECE Regulation No. 44 concerning the adoption of uniform conditions of approval and reciprocal recognition of approval for motor vehicle equipment and parts. (E/ECE/324, E/ECE/TRANS/505 Rev 1/Add 43, 22 January 1981).
2. The TNO child dummies P ¾, P 3, P 6 and P 10, TNO-report 1979.
3. Wismans, J., Stalnaker, R.L., Maltha, J.: Comparison study of two 3-year old child dummies (Part 572 and P3) in a harness type childs restraint system, 6th Ircobi conference, Salon de Provence, 1981.
4. Wismans, J., Maltha, J.: Comparison study of two 3-year old child dummies: the Part 572 and the P3. 25th AAAM conference, San Francisco, 1981.
5. Stalnaker, R.L., Maltha, J.: MADYMO used for Computer Aided Design of a dynamic acting child restraint seat. 5th Ircobi conference, Birmingham, 1980.
6. Wismans, J. et al.: Childs restraint evaluation by experimental and mathematical simulation. 23rd Stapp Car Crash Conference, San Diego, 1979.

Table A TEST RESULTS OF SEATS WITH HARNESS BELTS

product	3/4-year-old dummy							3-year-old dummy							6-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
A1	98	685	46	34	334	+29	yes	101	1253	52	36	389	+24	yes							
	76	643	41	29	310	+22	yes	113	1427	54	21	435	+ 3	yes							
	125	1248	48	29	384	+30	yes	74	494	59	28	468	+ 5	yes							
A2	66	633	30	20	206	- 6	yes	81	597	40	22	288	-27	yes							
	58	549	34	27	252	+ 0	yes	54	577	26	15	155	-21	yes							
	60	541	30	16	213	- 6	yes	48	511	30	16	222	-17	yes							
A3	85	897	41	18	351	+14	yes	84	681	38	17	306	+ 9	yes							
	87	810	37	16	294	+12	yes	63	604	34	18	242	+ 1	yes							
	62	501	32	23	244	+ 8	yes														
A4	67	569	36	18	298	+14	no	76	756	43	35	433	+ 5		69	550	38	34	230	- 3	no
	73	602	43	22	317	+14	no	68	696	37	24	288	+ 7		71	894	40	30	385	+ 3	no
															60	667	32	11	231	+ 0	no
A5	102	834	50	40	559	+13	no	52	407	34	19	263	+12	no	63	578	34	22	240	+ 6	no
	79	657	42	34	432	+16	no	57	465	36	25	299	+11	no	55	703	29	21	242	+ 6	no
								50	371	37	18	248	+11	no							
A1 averaged	100	859	45	31	342	+27	yes	96	1058	54	28	434	+11	yes							
A2 averaged	61	574	31	21	223	- 4	yes	61	561	32	18	222	-22	yes							
A3 averaged	78	736	37	19	296	+ 9	yes	75	643	36	18	274	+ 5	yes							
A4 averaged	70	586	40	20	308	+14	no	72	726	40	30	361	+ 6	no	67	703	37	25	282	+ 0	no
A5 averaged	91	746	46	37	496	+15	no	53	414	36	21	270	+11	no	59	641	32	22	241	+ 6	no
total averaged	80	705	38	25	323	+12	--	70	679	40	22	312	+ 2	--	63	677	35	24	264	+ 2	--

* A1, A2, A3 have no crotch strap and show abdominal penetration which is prevented by a crotch strap on A4, A5.

product	3/4-year-old dummy: resultant head acceleration (g)	3/4: HIC	3/4: 3-ms-level of result. chest acc. (g)	3/4: 3-ms-level of vert. chest acc. (g)	3/4: SI	3/4: head excursion (cm)	3/4: abdominal penetration	3-year-old dummy: resultant head acceleration (g)	3-yr: HIC	3-yr: 3-ms-level of result. chest acc. (g)	3-yr: 3-ms-level of vert. chest acc. (g)	3-yr: SI	3-yr: head excursion (cm)	3-yr: abdominal penetration	6-year-old dummy: resultant head acceleration (g)	6-yr: HIC	6-yr: 3-ms-level of result. chest acc. (g)	6-yr: 3-ms-level of vert. chest acc. (g)	6-yr: SI	6-yr: head excursion (cm)	6-yr: abdominal penetration
B1	85	850	78	18	350	+20	no	85	1120	48	10	350	+ 6	no	72	--	48	26	382	+20	yes
								77	960	52	12	369	+ 8	no	97	1343	71	46	--	+30	yes
B2	95	865	52	17	365	+15	no	74	380	56	13	350	+ 7	no	104	1130	56	22	388	+ 8	no
	78	635	50	12	329	+20	no	73	--	45	16	432	+13	no	78	--	40	22	397	+ 8	no
															69	989	42	14	311	+ 9	no
B1 averaged	85	850	78	18	350	+20		81	1040	50	11	360	+ 7		85	--	61	36	382	+25	
B2 averaged	86	750	51	15	347	+18		74	380	51	15	391	+10		84	1060	46	19	365	+ 8	
total averaged	86	790	60	16	348	+18		77	776	54	13	375	+ 9		84	1130	57	26	371	+15	

Table B TEST RESULTS OF SEATS USING ADULT 3-POINT BELTS

* Some of the HIC values are not reported (--) because the rebound shock of the head to the sled frame is taken into account. This is felt as unrealistic.

product	3/4-year-old dummy							3-year-old dummy							6-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
C1	75	710	35	13	256	+ 1	no	76	773	34	17	200	− 8	no	76	694	42	28	251	− 4	no
	85	685	36	14	275	− 1	no	91	937	37	17	286	− 7	no	79	666	45	19	278	−16	no
								65	766	30	10	183	− 1	no	81	899	43	20	250	−10	no
								87	957	42	18	287	+ 3	no							
								78	782	37	16	252	+ 2	no							
								72	582	40	22	275	+11	no							
								78	590	36	14	241	+ 6	no							
C2	52	509	21	20	109	− 8	no	75	623	31	21	224	−22	no	93	1032	26	24	176	−28	no
	61	611	21	20	127	− 8	no	64	666	30	21	184	−12	no							
C3	76	1050	34	16	207	−14	no	89	1108	56	26	320	−25	no							
	85	1305	31	16	173	−14	no	79	819	45	13	250	−18	no							
	89	1251	34	12	204	−18	no	90	1007	64	26	414	−27	no							
	70	1092	34	24	258	−16	no														
C4	92	507	38	10	257	+ 1	no	61	682	37	18	221	− 9	no							
	88	506	31	12	290	+10	no	48	254	31	12	157	−13	no							
	101	613	40	16	277	+13	no	55	431	40	10	251	−21	no							
C5	90	1660	31	23	269	−16	no	88	1116	46	26	312	−27	no							
	74	1221	38	27	267	−15	no	88	1010	40	14	234	−28	no							
	83	1486	40	28	282	−17	no	88	1088	48	24	356	−26	no							
C1 averaged	80	698	36	14	266	+ 0		78	770	37	16	246	+ 1		79	753	43	22	260	−10	
C2 averaged	57	560	22	20	118	− 8		70	645	31	21	204	−17		93	1032	26	24	176	−28	
C3–C5 averaged	81	1295	34	21	237	−16		87	1025	50	22	314	−25								
C4 averaged	94	542	35	13	275	+ 8		55	456	36	13	209	−14								
total averaged	81	872	33	18	232	−7		76	788	40	18	258	−12		82	822	39	23	239	−15	

Table C : TEST RESULTS OF SEATS WITH IMPACT BLOCK USING LAP BELTS

	3-year-old dummy							6-year-old dummy							10-year-old dummy						
product	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
D1	72	--	43	24	296	+22	yes	68	648	38	16	253	+10	yes							
	72	--	42	16	285	+24	yes	70	933	44	12	321	+ 8	yes							
D2	67	563	40	15	267	+10	yes	91	1056	56	14	416	-10	yes							
	66	536	34	16	248	+11	yes	97	1227	44	18	337	-10	yes							
	71	580	44	14	286	+12	yes														
D3								66	509	35	23	258	-12	yes	82	1131	44	24	353	+ 0	yes
								71	672	36	23	318	+ 4	yes	93	812	38	32	377	+ 6	yes
															70	911	50	18	455	+ 2	yes
D1 averaged	72	--	43	20	291	+23		69	791	41	14	287	+ 9								
D2 averaged	68	560	39	15	267	+11		94	1142	50	16	377	-10								
D3 averaged								69	590	36	23	288	- 4		82	951	44	26	395	+ 3	
total averaged	70	560	41	17	276	+15		77	840	42	18	317	- 2		82	951	44	26	395	+ 3	

Table D TEST RESULTS OF HARNESS BELT SYSTEM ONLY

product	3-year-old dummy: resultant head acceleration (g)	3-year-old dummy: HIC	3-year-old dummy: 3-ms-level of result. chest acc. (g)	3-year-old dummy: 3-ms-level of vert. chest acc. (g)	3-year-old dummy: SI	3-year-old dummy: head excursion (cm)	3-year-old dummy: abdominal penetration	6-year-old dummy: resultant head acceleration (g)	6-year-old dummy: HIC	6-year-old dummy: 3-ms-level of result. chest acc. (g)	6-year-old dummy: 3-ms-level of vert. chest acc. (g)	6-year-old dummy: SI	6-year-old dummy: head excursion (cm)	6-year-old dummy: abdominal penetration	10-year-old dummy: resultant head acceleration (g)	10-year-old dummy: HIC	10-year-old dummy: 3-ms-level of result. chest acc. (g)	10-year-old dummy: 3-ms-level of vert. chest acc. (g)	10-year-old dummy: SI	10-year-old dummy: head excursion (cm)	10-year-old dummy: abdominal penetration
E1	44	--	46	24	258	+ 4	no	49	231	42	10	230	+ 1	no	64	322	41	16	327	− 3	no
	59	559	50	23	308	+ 3	no	53	344	48	13	315	+12	no	41	243	54	20	388	− 9	no
															53	389	57	20	429	+ 3	no
E2	42	--	40	13	241	+12	no	59	375	48	12	514	+ 9	no	53	335	48	23	361	+10	no
	60	537	46	9	290	+22	no	59	323	41	17	280	+13	no	53	341	43	23	319	+17	no
								42	192	41	9	256	+ 6	no	76	388	48	25	388	+15	no
E3	89	1353	68	32	547	+ 8	yes	72	648	50	21	364	+30	yes	96	1208	59	29	588	+ 3	yes
	92	1254	68	28	499	+ 7	yes	84	958	71	33	682	+30	yes	89	1070	46	22	332	+ 7	yes
															85	602	52	24	443	− 1	yes
E4	120	1412	63	24	468	+ 6	yes	58	843	46	18	296	+20	yes	69	642	44	29	378	+13	yes
	90	1388	61	13	490	+ 8	yes	72	--	49	20	382	+20	yes	75	982	49	27	402	+ 7	yes
								70	--	57	28	568	+30	yes	72	855	58	39	509	+ 7	yes
E1 averaged	52	599	48	24	283	+ 4		51	288	45	12	273	+ 7		53	318	51	19	381	− 3	
E2 averaged	51	537	43	11	266	+17		53	297	43	13	350	+ 9		61	355	46	24	356	+14	
E3 averaged	91	1294	68	30	523	+ 8		78	798	61	27	523	+30		90	960	52	25	454	+ 4	
E4 averaged	105	1400	62	19	479	+ 7		67	843	51	22	415	+23		72	826	50	32	430	+ 9	
total averaged	75	1090	55	21	388	+ 9		63	489	49	18	389	+17		69	614	50	25	405	+ 6	

Table E TEST RESULTS OF BOOSTER SEATS USING ADULT 3-POINT BELTS

product	3-year-old dummy							6-year-old dummy							10-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
F1	93	1158	70	26	575	+15	yes	70	833	46	12	298	+13	yes	78	1017	66	14	530	+ 7	yes
	64	682	61	28	445	+20	yes	78	992	45	13	313	+15	yes	80	--	66	16	644	+14	yes
								88	1049	43	14	330	+16	yes							
F2	70	904	70	23	498	+15	yes	80	--	44	20	298	+11	yes							
	115	1200	60	25	494	+14	yes	85	--	64	20	540	+16	yes							
F3	108	1270	54	21	428	+11	yes	89	1504	50	34	447	+ 3	yes	82	--	56	18	452	+ 3	yes
	99	1172	47	20	392	+ 5	yes	95	1996	54	46	627	+ 5	yes	81	1666	46	16	399	+ 5	yes
F1-F2 averaged	86	986	65	26	503	+16		80	958	49	16	356	+14		79	1017	66	15	587	+11	
F3 averaged	104	1231	51	21	410	+ 8		92	1750	52	40	537	+ 4		82	1666	51	17	426	+ 4	
total averaged	92	1064	60	24	472	+13		84	1274	50	23	408	+11		80	1342	59	16	506	+ 7	

Table F TEST RESULTS OF ADULT 3-POINT BELTS WITH GUIDING STRAPS

Table A TEST RESULTS OF SEATS WITH HARNESS BELTS

product	3/4-year-old dummy							3-year-old dummy							6-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
A1	98	685	46	34	334	+29	yes	101	1253	52	36	389	+24	yes							
	76	643	41	29	310	+22	yes	113	1427	54	21	435	+ 3	yes							
	125	1248	48	29	384	+30	yes	74	494	59	28	468	+ 5	yes							
A2	66	633	30	20	206	- 6	yes	81	597	40	22	288	-27	yes							
	58	549	34	27	252	+ 0	yes	54	577	26	15	155	-21	yes							
	60	541	30	16	213	- 6	yes	48	511	30	16	222	-17	yes							
A3	85	897	41	18	351	+14	yes	84	681	38	17	306	+ 9	yes							
	87	810	37	16	294	+12	yes	63	604	34	18	242	+ 1	yes							
	62	501	32	23	244	+ 8	yes														
A4	67	569	36	18	298	+14	no	76	756	43	35	433	+ 5		69	550	38	34	230	- 3	no
	73	602	43	22	317	+14	no	68	696	37	24	288	+ 7		71	894	40	30	385	+ 3	no
															60	667	32	11	231	+ 0	no
A5	102	834	50	40	559	+13	no	52	407	34	19	263	+12	no	63	578	34	22	240	+ 6	no
	79	657	42	34	432	+16	no	57	465	36	25	299	+11	no	55	703	29	21	242	+ 6	no
								50	371	37	18	248	+11	no							
A1 averaged	100	859	45	31	342	+27	yes	96	1058	54	28	434	+11	yes							
A2 averaged	61	574	31	21	223	- 4	yes	61	561	32	18	222	-22	yes							
A3 averaged	78	736	37	19	296	+ 9	yes	75	643	36	18	274	+ 5	yes							
A4 averaged	70	586	40	20	308	+14	no	72	726	40	30	361	+ 6	no	67	703	37	25	282	+ 0	no
A5 averaged	91	746	46	37	496	+15	no	53	414	36	21	270	+11	no	59	641	32	22	241	+ 6	no
total averaged	80	705	38	25	323	+12	--	70	679	40	22	312	+ 2	--	63	677	35	24	264	+ 2	--

* A1, A2, A3 have no crotch strap and show abdominal penetration which is prevented by a crotch strap on A4, A5.

Table B TEST RESULTS OF SEATS USING ADULT 3-POINT BELTS

product	3/4-year-old dummy							3-year-old dummy							6-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
B1	85	850	78	18	350	+20	no	85	1120	48	10	350	+ 6	no	72	--	48	26	382	+20	yes
								77	960	52	12	369	+ 8	no	97	1343	71	46	--	+30	yes
B2	95	865	52	17	365	+15	no	74	380	56	13	350	+ 7	no	104	1130	56	22	388	+ 8	no
	78	635	50	12	329	+20	no	73	--	45	16	432	+13	no	78	--	40	22	397	+ 8	no
															69	989	42	14	311	+ 9	no
B1 averaged	85	850	78	18	350	+20		81	1040	50	11	360	+ 7		85	--	61	36	382	+25	
B2 averaged	86	750	51	15	347	+18		74	380	51	15	391	+10		84	1060	46	19	365	+ 8	
total averaged	86	790	60	16	348	+18		77	776	54	13	375	+ 9		84	1130	57	26	371	+15	

* Some of the HIC values are not reported (--) because the rebound shock of the head to the sled frame is taken into account. This is felt as unrealistic.

Table C : TEST RESULTS OF SEATS WITH INPACT BLOCK USING LAP BELTS

product	3/4-year-old dummy							3-year-old dummy							6-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
C1	75	710	35	13	256	+ 1	no	76	773	34	17	200	- 8	no	76	694	42	28	251	- 4	no
	85	685	36	14	275	- 1	no	91	937	37	17	286	- 7	no	79	666	45	19	278	-16	no
								65	766	30	10	183	- 1	no	81	899	43	20	250	-10	no
								87	957	42	18	287	+ 3	no							
								78	782	37	16	252	+ 2	no							
								72	582	40	22	275	+11	no							
								78	590	36	14	241	+ 6	no							
C2	52	509	21	20	109	- 8	no	75	623	31	21	224	-22	no	93	1032	26	24	176	-28	no
	61	611	21	20	127	- 8	no	64	666	30	21	184	-12	no							
C3	76	1050	34	16	207	-14	no	89	1108	56	26	320	-25	no							
	85	1305	31	16	173	-14	no	79	819	45	13	250	-18	no							
	89	1251	34	12	204	-18	no	90	1007	64	26	414	-27	no							
	70	1092	34	24	258	-16	no														
C4	92	507	38	10	257	+ 1	no	61	682	37	18	221	- 9	no							
	88	506	31	12	290	+10	no	48	254	31	12	157	-13	no							
	101	613	40	16	277	+13	no	55	431	40	10	251	-21	no							
C5	90	1660	31	23	269	-16	no	88	1116	46	26	312	-27	no							
	74	1221	38	27	267	-15	no	88	1010	40	14	234	-28	no							
	83	1486	40	28	282	-17	no	88	1088	48	24	356	-26	no							
C1 averaged	80	698	36	14	266	+ 0		78	770	37	16	246	+ 1		79	753	43	22	260	-10	
C2 averaged	57	560	22	20	118	- 8		70	645	31	21	204	-17		93	1032	26	24	176	-28	
C3-C5 averaged	81	1295	34	21	237	-16		87	1025	50	22	314	-25								
C4 averaged	94	542	35	13	275	+ 8		55	456	36	13	209	-14								
total averaged	81	872	33	18	232	-7		76	788	40	18	258	-12		82	822	39	23	239	-15	

Table D TEST RESULTS OF HARNESS BELT SYSTEM ONLY

	3-year-old dummy							6-year-old dummy							10-year-old dummy						
product	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
D1	72	--	43	24	296	+22	yes	68	648	38	16	253	+10	yes							
	72	--	42	16	285	+24	yes	70	933	44	12	321	+ 8	yes							
D2	67	563	40	15	267	+10	yes	91	1056	56	14	416	-10	yes							
	66	536	34	16	248	+11	yes	97	1227	44	18	337	-10	yes							
	71	580	44	14	286	+12	yes														
D3								66	509	35	23	258	-12	yes	82	1131	44	24	353	+ 0	yes
								71	672	36	23	318	+ 4	yes	93	812	38	32	377	+ 6	yes
															70	911	50	18	455	+ 2	yes
D1 averaged	72	--	43	20	291	+23		69	791	41	14	287	+ 9								
D2 averaged	68	560	39	15	267	+11		94	1142	50	16	377	-10								
D3 averaged								69	590	36	23	288	- 4		82	951	44	26	395	+ 3	
total averaged	70	560	41	17	276	+15		77	840	42	18	317	- 2		82	951	44	26	395	+ 3	

Table E TEST RESULTS OF BOOSTER SEATS USING ADULT 3-POINT BELTS

product	3-year-old dummy							6-year-old dummy							10-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
E1	44	--	46	24	258	+ 4	no	49	231	42	10	230	+ 1	no	64	322	41	16	327	- 3	no
	59	559	50	23	308	+ 3	no	53	344	48	13	315	+12	no	41	243	54	20	388	- 9	no
															53	389	57	20	429	+ 3	no
E2	42	--	40	13	241	+12	no	59	375	48	12	514	+ 9	no	53	335	48	23	361	+10	no
	60	537	46	9	290	+22	no	59	323	41	17	280	+13	no	53	341	43	23	319	+17	no
								42	192	41	9	256	+ 6	no	76	388	48	25	388	+15	no
E3	89	1353	68	32	547	+ 8	yes	72	648	50	21	364	+30	yes	96	1208	59	29	588	+ 3	yes
	92	1254	68	28	499	+ 7	yes	84	958	71	33	682	+30	yes	89	1070	46	22	332	+ 7	yes
															85	602	52	24	443	- 1	yes
E4	120	1412	63	24	468	+ 6	yes	58	843	46	18	296	+20	yes	69	642	44	29	378	+13	yes
	90	1388	61	13	490	+ 8	yes	72	--	49	20	382	+20	yes	75	982	49	27	402	+ 7	yes
								70	--	57	28	568	+30	yes	72	855	58	39	509	+ 7	yes
E1 averaged	52	599	48	24	283	+ 4		51	288	45	12	273	+ 7		53	318	51	19	381	- 3	
E2 averaged	51	537	43	11	266	+17		53	297	43	13	350	+ 9		61	355	46	24	356	+14	
E3 averaged	91	1294	68	30	523	+ 8		78	798	61	27	523	+30		90	960	52	25	454	+ 4	
E4 averaged	105	1400	62	19	479	+ 7		67	843	51	22	415	+23		72	826	50	32	430	+ 9	
total averaged	75	1090	55	21	388	+ 9		63	489	49	18	389	+17		69	614	50	25	405	+ 6	

Table F TEST RESULTS OF ADULT 3-POINT BELTS WITH GUIDING STRAPS

product	3-year-old dummy							6-year-old dummy							10-year-old dummy						
	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration	resultant head acceleration (g)	HIC	3-ms-level of result. chest acc. (g)	3-ms-level of vert. chest acc. (g)	SI	head excursion (cm)	abdominal penetration
F1	93	1158	70	26	575	+15	yes	70	833	46	12	298	+13	yes	78	1017	66	14	530	+ 7	yes
	64	682	61	28	445	+20	yes	78	992	45	13	313	+15	yes	80	--	66	16	644	+14	yes
								88	1049	43	14	330	+16	yes							
F2	70	904	70	23	498	+15	yes	80	--	44	20	298	+11	yes							
	115	1200	60	25	494	+14	yes	85	--	64	20	540	+16	yes							
F3	108	1270	54	21	428	+11	yes	89	1504	50	34	447	+ 3	yes	82	--	56	18	452	+ 3	yes
	99	1172	47	20	392	+ 5	yes	95	1996	54	46	627	+ 5	yes	81	1666	46	16	399	+ 5	yes
F1-F2 averaged	86	986	65	26	503	+16		80	958	49	16	356	+14		79	1017	66	15	587	+11	
F3 averaged	104	1231	51	21	410	+ 8		92	1750	52	40	537	+ 4		82	1666	51	17	426	+ 4	
total averaged	92	1064	60	24	472	+13		84	1274	50	23	408	+11		80	1342	59	16	506	+ 7	