Human Tolerance to Lateral Impact With Lap Belt Only°

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ABSTRACT

A series of controlled deceleration experiments was performed with 37 human male volunteers to determine, if possible, human tolerance to lateral impacts while restrained in a seat with a lap belt. The subjects were exposed in 50 different experiments at average impact G of 3.25 to 9.02 for durations of 0.3 to 0.1 seconds. No permanent physiological changes were noted. Minor physical complaints were reported by 50 per cent of the subjects when exposed to 6.25 average G or more. Increasing danger from lateral flexion of up to 30° from the vertical halted the experiments at the 9.02 average G.

INTRODUCTION

The lap belt (i.e. seat belt, safety belt) is a typical occupant-restraining device in many of the common passenger vehicles. This simple, inexpensive protective device is installed and used in aircraft, automobiles, and other vehicles where some restraint is required either for protection in collision or for better control of the vehicle under random and unpredictable oscillation, such as that produced by turbulent air in flight.

The device is simple; consequently, it is possibly used in applications where it offers no improvement in protection or where its use may even be injurious to the occupant.

The use of lap-belt restraining devices has been investigated for force vectors applied to the body in the transverse direction (i.e. front to back or back to front) and general limitations of the system are known for this case (Stapp, 1949; Stapp, 1957).

° Acknowledgment is gratefully made to the participating subjects without whom this investigation would have been impossible and to the Air Force Medical Monitors.

Unfortunately, the lap belt is also being used where the force vector is applied laterally to the body (i.e., left to right or right to left). These cases include the use in automobiles at the time of an intersection collision and in passenger aircraft where there is a sideward-facing lounge seat (Severy et al, 1959; FAA, 1963; Dubois, 1952).

PURPOSE

Some investigation has been accomplished on defining human limitations to lateral impacts. In all cases the restraints have varied, but essentially all provide greater restriction of motion to the entire torso than the lap belt. Usually some limb restraint is added (Weis et al, 1963).

The purpose of this study is to investigate and, if possible, to define human tolerance to lateral impacts based on physiological and kinematic end points. These end points are defined as follows:

a. Abnormal changes from a pre-run medical examination that includes evaluation of the musculoskeletal, cardiovascular, respiratory, and nervous system.

b. Abnormal physiologic changes as indicated on electrocardiogram, blood pressure, and respiration records taken during the experiment.

c. Excessive lumbar flexion as recorded on film.

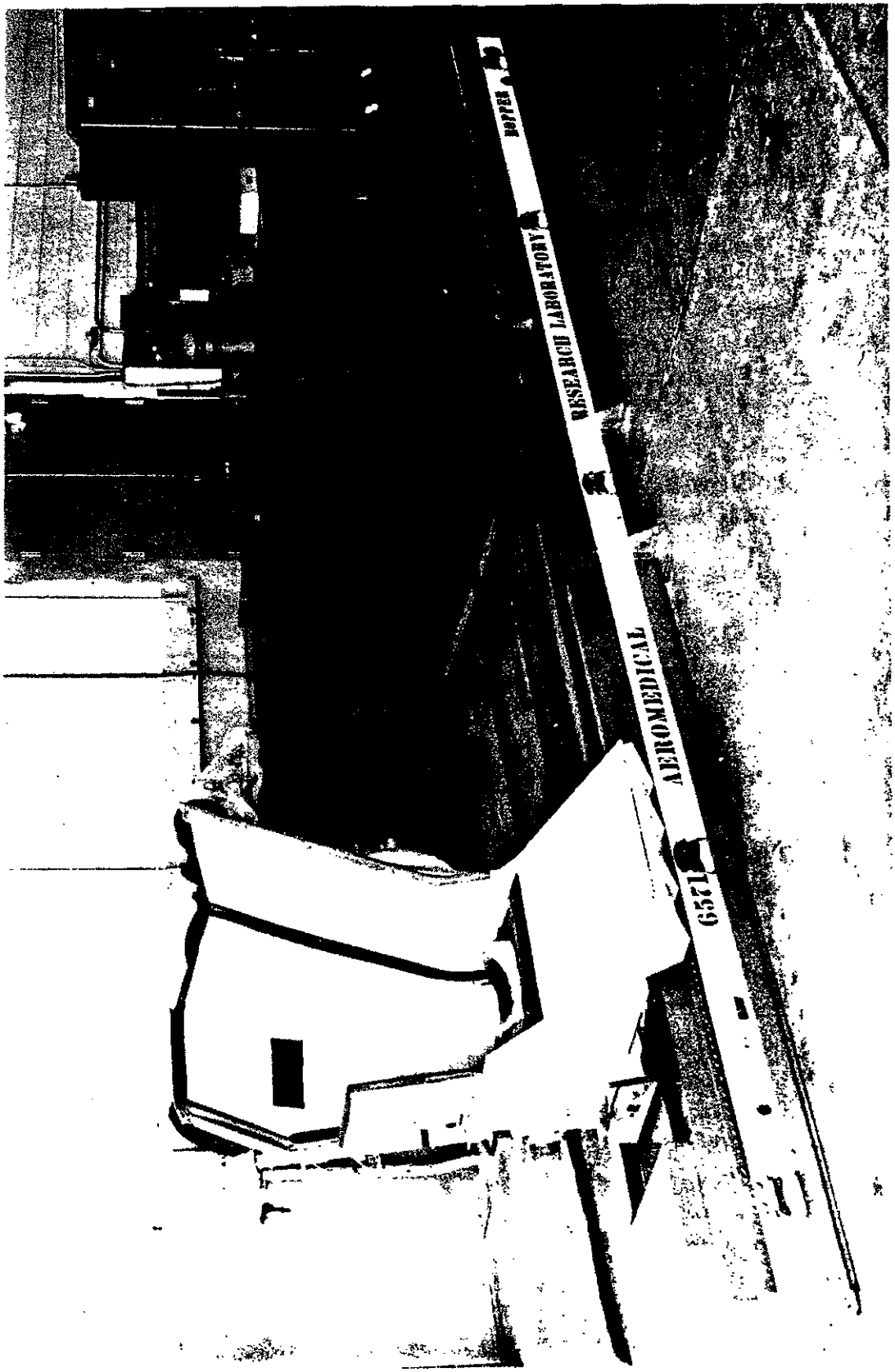
d. Reports of discomfort by subjects or persistent localized pain.

MATERIALS

This series of experiments required the use of (a) a controllable, reproducible deceleration device; (b) a system for recording physiological, physical, and kinematic data for later analysis; and (c) a group of volunteer human subjects.

The deceleration device used was the 6571st Aeromedical Research Laboratory Biodynamics Division's Crash Restraint Demonstrator commonly known as the Bopper (Figure 1). The Bopper is a bungee-propelled seat-sled system with a programmable mechanical friction brake. The seat was positioned with the back parallel to the direction of travel and the subject so faced that his left shoulder pointed in the direction of travel. The seat, built to dimensions specified in Military Specification – Seat: Upward Ejection, Aircraft MIL-S-9479 (USAF) 19 March 1954 with a 12° seat-back angle, was modified with a left side plate of light construction and padded with ½ inch Insulite. The left side plate was set at a 30° angle from the vertical and joined the side of the seat at a distance of 4 inches above the seat cushion at 18 inches from the back (Figure 2). This angle was determined as the maximum angle allowable of lateral spinal flexion without

FIGURE 1. Crash Restraint Demonstrator.
The seat mounted on the sled is in the firing position (left foreground). Physical and physiological recording systems (right foreground).



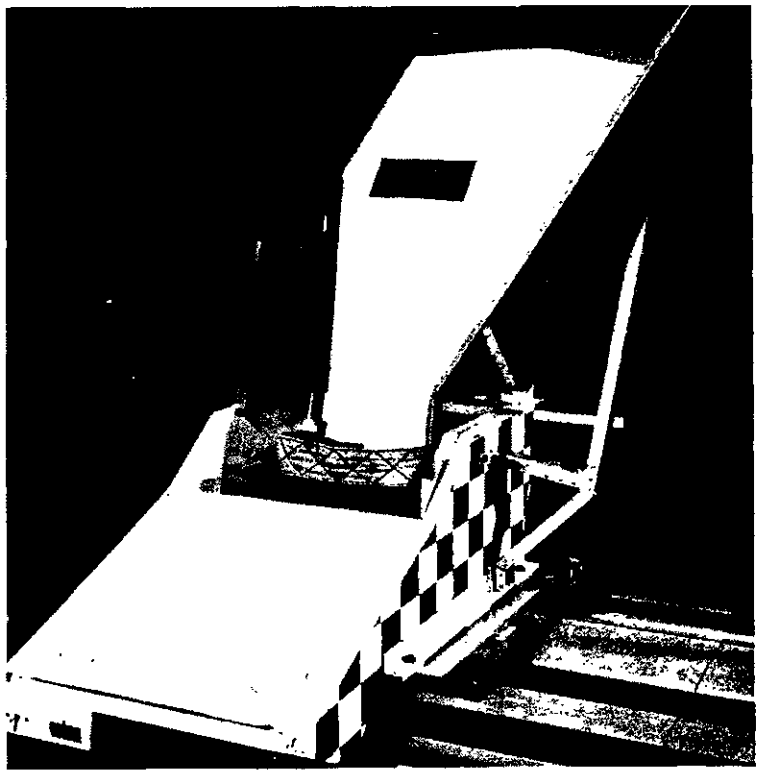


FIGURE 2. Detail of Bopper Seat.

The Bopper seat was modified with a left 30° side plate. The right side plate and lap belt are also shown.

injury (Dempster, 1955). After Run 2444, the seat was further modified with a right side plate that extended 19 inches above the seat cushion and 11 inches in front of and parallel to the seat back. The function of this modification was to assist the subject in maintaining an upward position during the acceleration phase of the run.

The subject was restrained by a single continuous lap belt fabricated with two layers of 3-inch-wide Polyester with Nylon filling, single twill-weave Type IV webbing of 8700 pounds breaking strength. The webbing conforms to Military Specification MIL-W-25361. The webbing was sewn with ¼ inch spaced stitching ¼ inch parallel to each edge and in a diagonal diamond shape on 3-inch centers. The assembly exhibited a breaking strength of 14,000 pounds and elongations of 6.3 per cent at 4,000 pounds, 9 per cent at 8,000 pounds and 12.5 per cent at 12,000 pounds. All data was from one static test only.

Physical data were recorded from strain-gage type accelerometers fixed to the sled, to the seat, and attached to the subject. All accelerometers were oriented in the three primary axes. For the sled system: X direction is a vector in the direction of travel; Y is 90° perpendicular to X in the horizontal plane and pointing right; while Z is in the vertical plane pointing upward

FIGURE 3. Instrumented subject in Seat Prior to Test.

Subject has assumed typical position for test. Photograph shows triaxial accelerometer head mount, position of electroencephalogram electrodes on forehead, respiration sensor under nose, triaxial accelerometer pack on chest, automatic blood pressure cuff on right arm and position of the lap belt.

90° from X. To the subject the X direction is perpendicular to the anterior-posterior plane and the same relationship of Y to X and Z to X exists as described for the sled.

The sled was instrumented with a single accelerometer for the X vector. Statham Type A-6 accelerometers were used in all cases.

SUBJECTS

For this series of tests 37 male Air Force volunteers (Table 1) were used with an average age of 27 years, a range of 20 to 42 years, an average weight of 162 pounds (73 kg) and a range of 119 pounds (54 kg) to 209 pounds (95 kg). All subjects had undergone a rigorous physical examination (Air Force Class III Flight Physical) and additional tests. These tests were a detailed radiographic examination of spine, tonometric examination of eye, and baseline electroencephalogram.

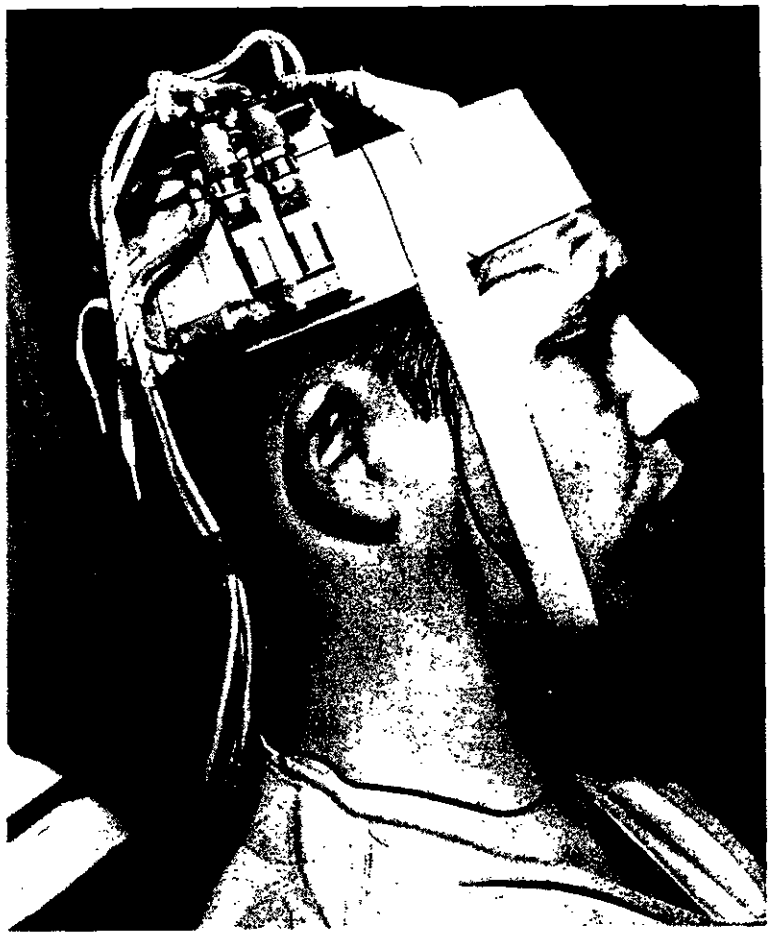


FIGURE 4. Detail of Triaxial Head Accelerometer Mount in Place.

METHOD

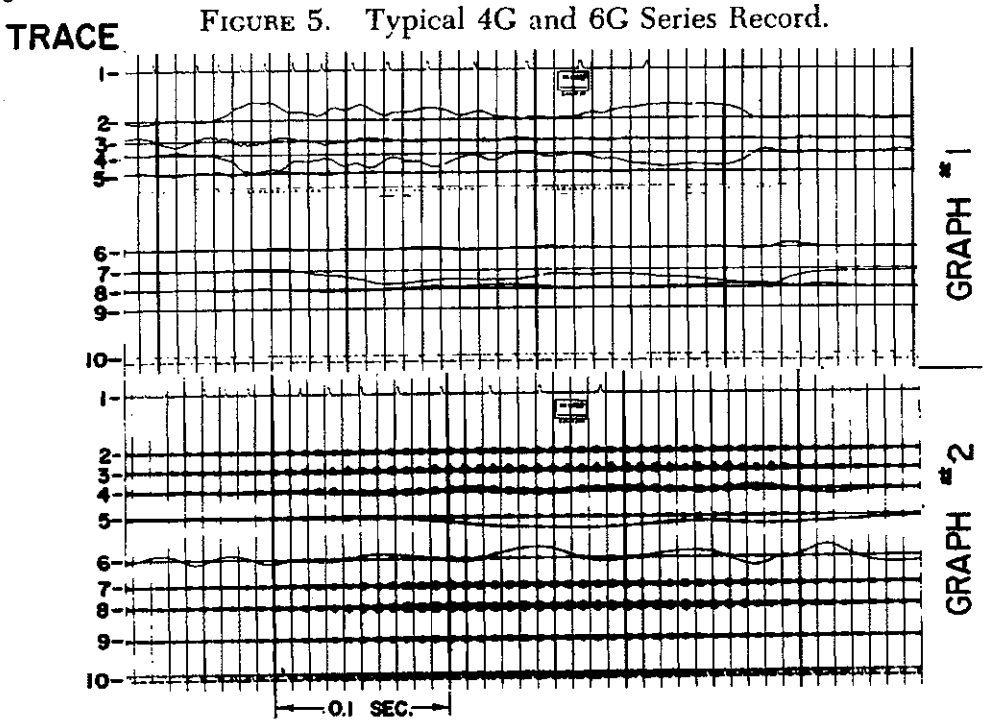
A series of tests was scheduled beginning with a 4 G plateau deceleration pattern and continuing at 2 G increments until it appeared that a tolerance level based on the established criteria had been reached.

The Bopper brake was set and calibration runs were made with an Alderson Anthropomorphic Dummy, Model F-5, instrumented with accelerometers internally and externally mounted to establish the specific brake pattern. Deceleration profile data were obtained from the sled-mounted accelerometer.

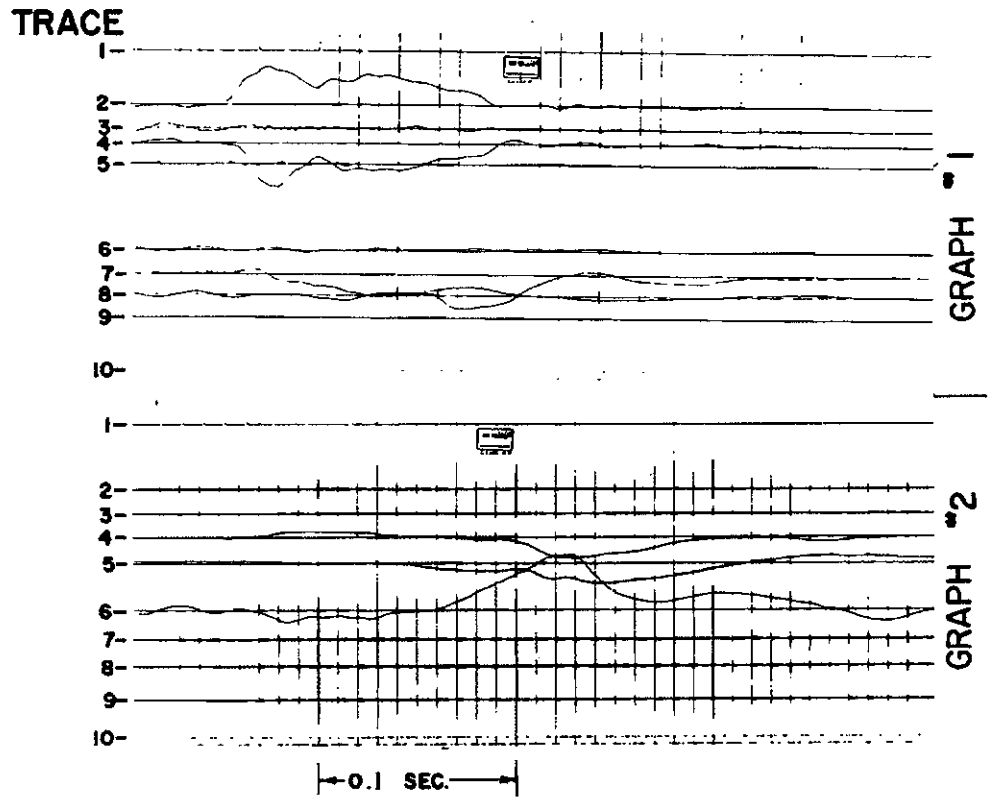
Subjects were instructed to be well rested and not to have taken any solids or fluids since midnight preceding the test day. In general, experiments were scheduled beginning at 8 A.M. and a series of 8 to 10 runs was accomplished on any one day.

On arrival at the test site the pre-run physical examination was made

FIGURE 5. Typical 4G and 6G Series Record.



TYPICAL 4 G SERIES RECORD RUN #2438

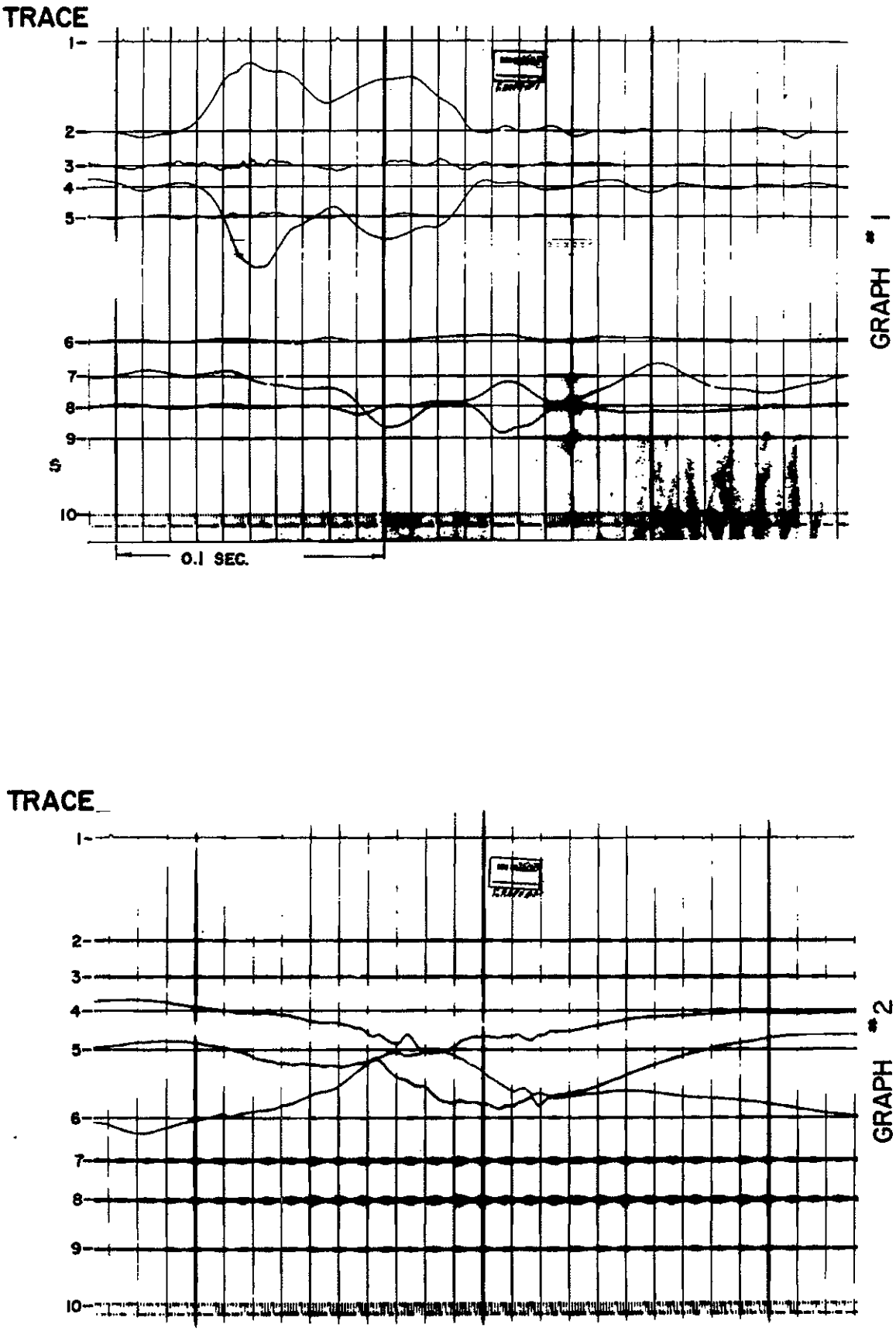


TYPICAL 6 G SERIES RECORD RUN #2455

TABLE 1
SELECTED ANTHROPOMORPHIC DATA

Subject	Age (yrs)	Weight		Standing Height		Sitting Height		Chest Circumference		Waist Circumference		Buttock Breadth	
		lbs	(kg)	inches	(cm)	inches	(cm)	inches	(cm)	inches	(cm)	inches	(cm)
DNA	28	128.5	(58.41)	65.1	(165.3)	32.7	(83.2)	34.1	(86.5)	31.3	(79.4)	13.5	(34.4)
GVA	26	119	(54.09)	64.8	(164.7)	34.9	(88.6)	32.9	(83.8)	27.7	(70.3)	12.5	(31.7)
JLA	29	150	(68.18)	65.7	(169.9)	35.4	(89.5)	35.9	(91.4)	31.2	(79.3)	14.3	(36.4)
WNA	34	197	(89.55)	69.8	(177.3)	35.6	(90.5)	41.1	(106.9)	37.4	(95.0)	16.1	(40.8)
JRB	23	130	(59.09)	71	(180.51)	35.1	(89.2)	33.3	(84.7)	26.9	(68.3)	12.8	(32.5)
RJB	31	171	(77.73)	67.7	(174.6)	35.8	(90.9)	38.2	(97.0)	36.8	(93.5)	15.1	(38.4)
CAC	33	152	(69.09)	67.1	(170.5)	34.4	(87.3)	37.4	(95.0)	34.7	(88.2)	14.1	(35.8)
FJC	24	166	(75.45)	68.9	(175.2)	35.9	(91.3)	37.0	(94.0)	33.8	(86.0)	14.4	(36.6)
GWC	20	174.5	(79.32)	67.4	(171.2)	35.6	(90.3)	37.8	(96.0)	33.5	(85.0)	14.3	(36.2)
WCC	27	181.5	(82.50)	66.3	(168.3)	34.6	(87.8)	39.9	(101.5)	39.2	(99.5)	15.7	(40.0)
SMcD	23	124.5	(56.59)	65.4	(166.2)	33.3	(84.6)	31.5	(80.0)	26.3	(66.8)	12.2	(31.0)
RWD	28	165.5	(75.23)	65.4	(166.2)	35.7	(90.7)	39.9	(101.5)	35.2	(89.5)	14.8	(37.5)
JOE	24	179.5	(81.59)	69.1	(175.5)	35.9	(91.3)	39.4	(100.0)	38.8	(93.5)	15.3	(38.8)
PF	22	135.3	(61.50)	71.7	(182.0)	35.9	(91.3)	33.5	(85.0)	26.8	(68.0)	12.5	(31.8)
YSF	25	208.5	(94.77)	67.7	(172.0)	35.6	(90.5)	42.1	(107.0)	39.9	(101.3)	16.5	(41.8)
GAG	26	178.0	(80.91)	67.9	(172.6)	36.2	(92.0)	39.5	(100.4)	33.7	(85.5)	14.6	(37.0)
WG	37	130.8	(59.45)	63.8	(162.1)	33.1	(84.1)	33.5	(85.0)	28.5	(72.5)	12.4	(31.5)
CWH	24	156.5	(71.14)	70.8	(179.8)	36.8	(93.6)	37.3	(94.8)	31.8	(80.7)	15.7	(39.9)
KDH	32	182.3	(82.86)	71.7	(182.1)	36.3	(92.3)	40.1	(102.0)	36.0	(91.5)	15.8	(40.2)
CRM	33	163	(74.09)	69.3	(175.9)	35.9	(91.2)	38.0	(96.6)	34.0	(86.4)	14.6	(37.0)
CGO	26	157	(71.36)	71.4	(181.3)	37.4	(95.0)	37.0	(94.0)	32.5	(82.6)	14.8	(37.5)
JLP	21	164	(74.55)	69.9	(177.8)	35.4	(89.8)	37.9	(96.5)	32.4	(82.2)	14.1	(35.8)
JWP	26	191	(86.82)	69.1	(175.4)	36.1	(91.6)	40.7	(103.5)	36.5	(92.6)	14.3	(36.4)
CR	27	183	(83.18)	66.7	(169.3)	35.4	(90.0)	40.5	(103.0)	39.3	(99.9)	14.8	(37.7)
CAR	22	158.8	(72.18)	68.1	(173.0)	36.1	(91.7)	37.6	(95.5)	31.1	(79.0)	14.3	(36.4)
CAR	26	202.8	(92.18)	71.5	(181.6)	36.5	(92.6)	41.5	(105.5)	36.1	(91.8)	15.4	(39.0)
JWR	22	150.8	(68.55)	70.1	(178.1)	36.8	(93.5)	37.9	(96.5)	29.1	(73.8)	14.3	(36.2)
RR	22	125.0	(56.82)	66.4	(168.7)	35.1	(89.2)	33.1	(84.2)	30.1	(76.5)	13.2	(33.4)
ERS	24	186.0	(84.55)	67.4	(171.2)	35.8	(91.0)	40.9	(104.0)	38.1	(96.7)	15.6	(39.5)
GOS	23	158.5	(72.05)	64.9	(165.0)	34.1	(86.7)	37.5	(95.2)	33.5	(85.1)	15.4	(39.0)
JHS	42	141	(64.09)	68.3	(173.5)	33.2	(84.3)	36.6	(93.0)	31.1	(74.0)	13.5	(34.2)
JDT	31	162.8	(74.00)	69.8	(177.4)	37.7	(95.8)	36.9	(93.7)	33.7	(85.7)	13.1	(33.2)
TRT	22	163	(74.09)	70.8	(179.9)	37.2	(94.4)	35.5	(90.2)	32.7	(83.2)	14.4	(36.7)
WCT	41	140	(163.64)	66.1	(167.9)	35.2	(89.3)	36.2	(91.9)	31.8	(80.8)	14.2	(36.0)
WHT	24	167.0	(75.91)	66.9	(170.0)	35.7	(90.6)	37.0	(94.0)	34.6	(88.0)	15.1	(38.3)
GJV	30	148	(67.27)	69.1	(175.4)	Not Available							
JPW	31	185	(84.09)	70.6	(179.4)	36.2	(92.0)	39.3	(9.90)	32.7	(84.0)	14.7	(37.2)

FIGURE 6. Typical 8 G Series Record.

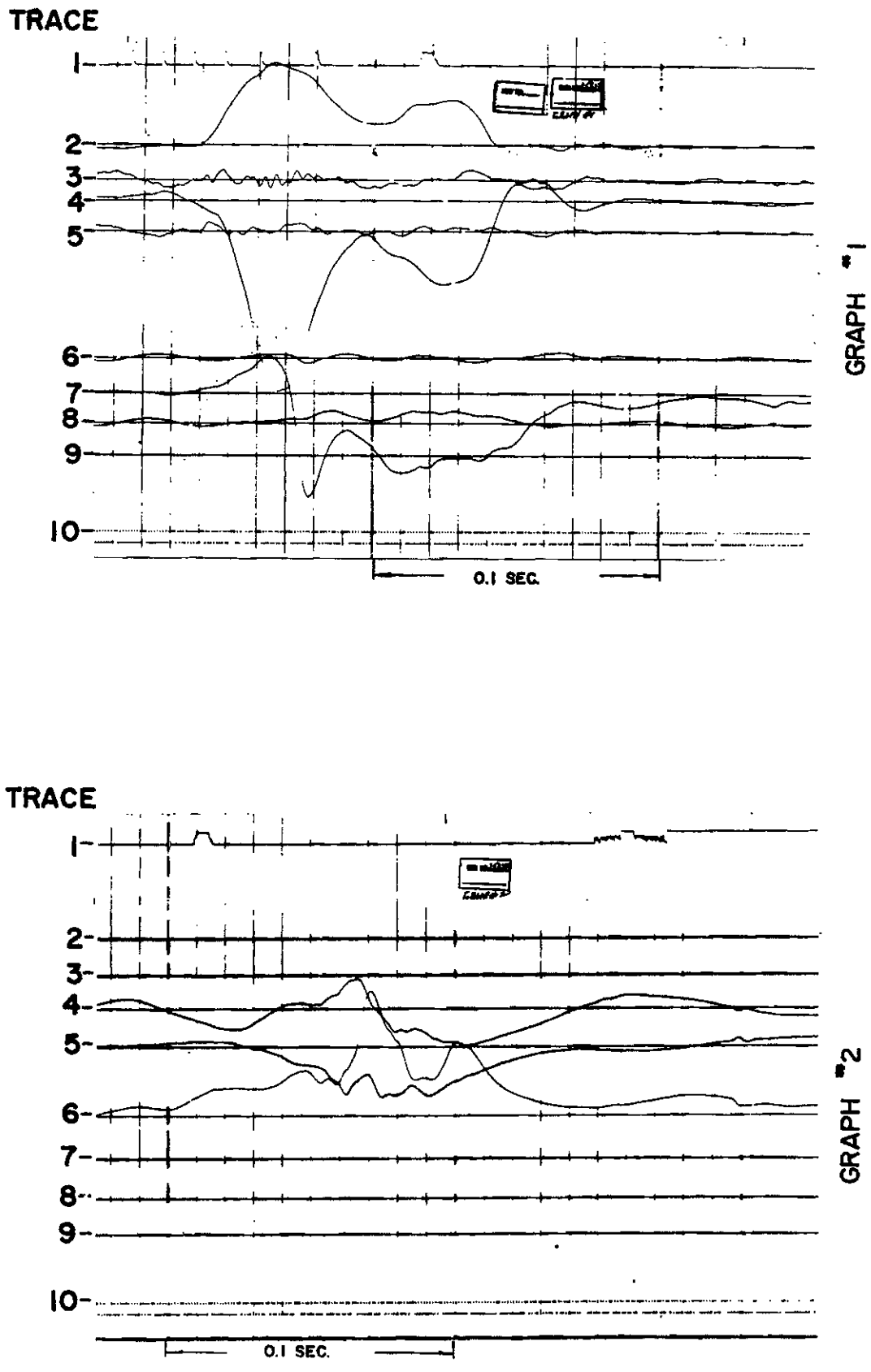


(Appendix – Attending Physician Report Form), the subject was instrumented for physiological data, led to the sled, and strapped in. The lap belt was fitted snugly over the iliac crest of the pelvis. The subject was given instructions on riding position, i.e., to be tensed or relaxed; how to hold his hands and feet. In general, hands were clasped together in the lap and feet were placed against the foot rests (Figure 3). Then calibrations were performed and a complete series of electronic physiological data was made. A brief countdown procedure was then initiated of 20 seconds duration, during which time all instrumentation was operating and continued oper-

TABLE 2
SUBJECTS RUN LOG

	Programmed G Level							
	4		6		8		10	
Subject	Run	Accumulated G	Run	Accumulated G	Run	Accumulated G	Run	Accumulated G
WNA	2,432	(111)						
JLA	2,433	(154)			2,503	(173)		
WCT	2,434	(111)			2,494	(143)		
JPW	2,435	(524)			2,497	(547)	2,541	(565)
JWP	2,436	(154)			2,495	(181)	2,540	(198)
CGO	2,438	(134)						
CAR	2,439	(536)					2,531	(554)
ERS	2,440	(193)					2,530	(207)
WHT	2,441	(538)					2,533	(554)
SMcD	2,442	(493)			2,492	(534)		
FJC	2,443	(520)					2,545	(543)
GWC	2,444	(235)					2,538	(257)
JOE			2,453	(224)			2,527	(238)
PF			2,454	(81)				
DNA			2,455	(311)	2,510	(335)		
KDH			2,456	(545)				
JDT			2,457	(221)	2,509	(241)		
JRB			2,458	(416)	2,506	(456)		
TRT			2,459	(187)			2,532	(210)
WCC			2,460	(505)			2,543	(526)
YSF			2,461	(149)			2,542	(165)
JWR			2,462	(328)	2,491	(353)		
RJB			2,476	(430)	2,496	(452)		
CAC			2,477	(160)	2,505	(199)		
CRM			2,478	(205)	2,508	(226)	2,539	(244)
JHS			2,479	(537)	2,511	(576)	2,526	(601)
CWH			2,480	(218)	2,507	(239)		
GCS			2,481	(303)			2,546	(324)
RR			2,482	(198)	2512	(224)		
CR			2,483	(396)			2,534	(412)
GJV					2,493	(241)		
WG					2,498	(626)	2,544	(659)
GVA					2,499	(231)		
RWD					2,500	(526)		
GAG					2,504	(443)	2,537	(460)
JLP							2,528	(244)
GAR							2,529	(402)

FIGURE 7. Typical 10 G Series Record.



ating a minimum of 40 seconds post-impact. The sled system was then fired, and immediately after impact the lap belt was loosened, post-run calibrations were made, and physiological data collected. Total time of the experiment, in general, was approximately 3 minutes. The subject was then released from the seat and the post-run physical examination was completed. The subject then reported his experiences and after-effects in a subjective report 72 hours post-run (Appendix – Subjective Report Guide).

TABLE 3
CALIBRATION (G/in)

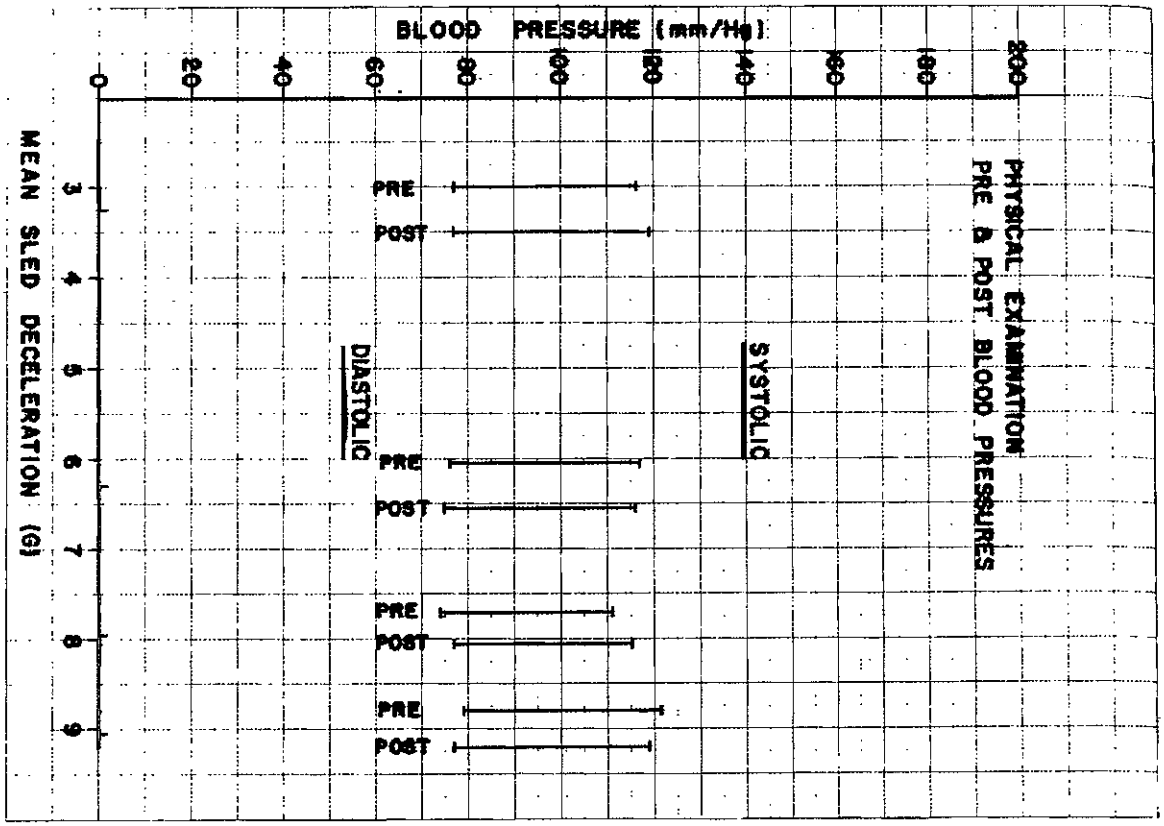
Graph I	Function	Run 2438	Run 2455	Run 2510	Run 2532
Trace 1	Brake Penetration	—	—	—	—
2	Sled X Acceleration	5	5	5	5
3	Seat X Acceleration	10	10	5	5
4	Seat Y Acceleration	5	5	5	2½
5	Seat Z Acceleration	10	20	5	5
6	Chest X Acceleration	10	10	10	2½
7	Chest Y Acceleration	20	20	20	10
8	Chest Z Acceleration	10	10	10	5
9	Not Used	—	—	—	—
10	IRIG "A" Format Time	—	—	—	—
Graph II					
Trace 1	Brake Penetration	—	—	—	—
2	Not Used	—	—	—	—
3	Not Used	—	—	—	—
4	Head X Acceleration	5	5	5	5
5	Head Y Acceleration	10	10	5	10
6	Head Z Acceleration	5	5	5	5
7	Not Used	—	—	—	—
8	Not Used	—	—	—	—
9	Not Used	—	—	—	—
10	IRIG "A" Format Time	—	—	—	—

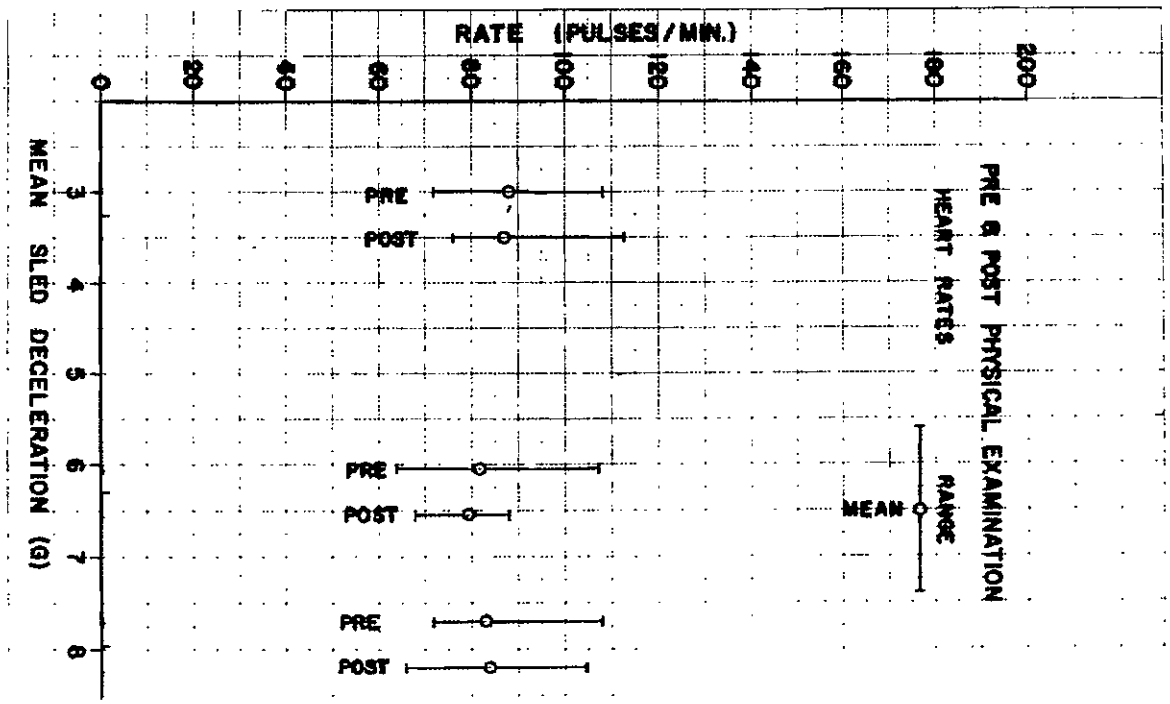
The seat was instrumented with a triaxial cluster of Statham Type A-6 accelerometers attached to the seat back posterior to the subject approximately in line with the subject's sternum, with the same axes orientation as the subject.

The subjects (Figures 3 and 4) were instrumented both for chest and head acceleration. Strapped tightly over the subject's sternum was a triaxial accelerometer pack of the Statham Type A-6. An adjustable harness was designed and fabricated to hold a triaxial pack of Statham A-52 accelerometers over the right temporal region of the head.

All accelerometer transducer data were recorded on a Consolidated Electrodynamics Oscillograph Type 5-119 equipped with 135 cps galvanometers for the acceleration traces with a paper speed of 63 in/sec (2.06 m/sec).

FIGURE 8. Average Blood Pressures and Heart Rates – Pre- and Post-Run Physical Examination by Run Series.





Kinematic data were recorded with 16 mm Ippollito High Speed Cameras operating at 2,000 fps. The cameras were positioned to photograph a top and side view (front of the subject) of the decelerator's brake area.

The subjects physiological responses were measured with instrumentation for blood pressure, electrocardiogram, electroencephalogram, and respiration rate.

The automatic blood-pressure system is an in-house contractor-developed device by Dynalectron Inc., using an automatically inflatable cuff and sensor microphone. The assembly was attached to the subject's right upper arm.

The electrocardiograph is a single-channel system with electrodes located over the sternum, on the lower back at L-5, and a ground lead over the thoracic vertebra at T-8. Sandborn Redux Electrode paste was used, and the electrodes were attached with tape.

The electroencephalogram, actually no more than an electro-oculomyogram in this case, was obtained from electrodes placed on the right and left temporal regions of the head and T-8 was again the ground lead. Sandborn Redux paste was also used and the electrodes were taped to the subject.

Respiration rate was obtained from the subject with a Yellow Springs Air Temperature Probe (405) taped under the subject's nostril.

All physiological data were recorded on a Sandborn 305 unit with a paper speed of 25 mm/sec.

Four series of runs (Table 2) were made with 12 tests at 4 G, 18 tests at 6 G, 20 tests at 8 G, and 20 tests at the 10 G level.

Some subjects rode in more than one experiment, but never at the same level or at an interval of less than one week between tests.

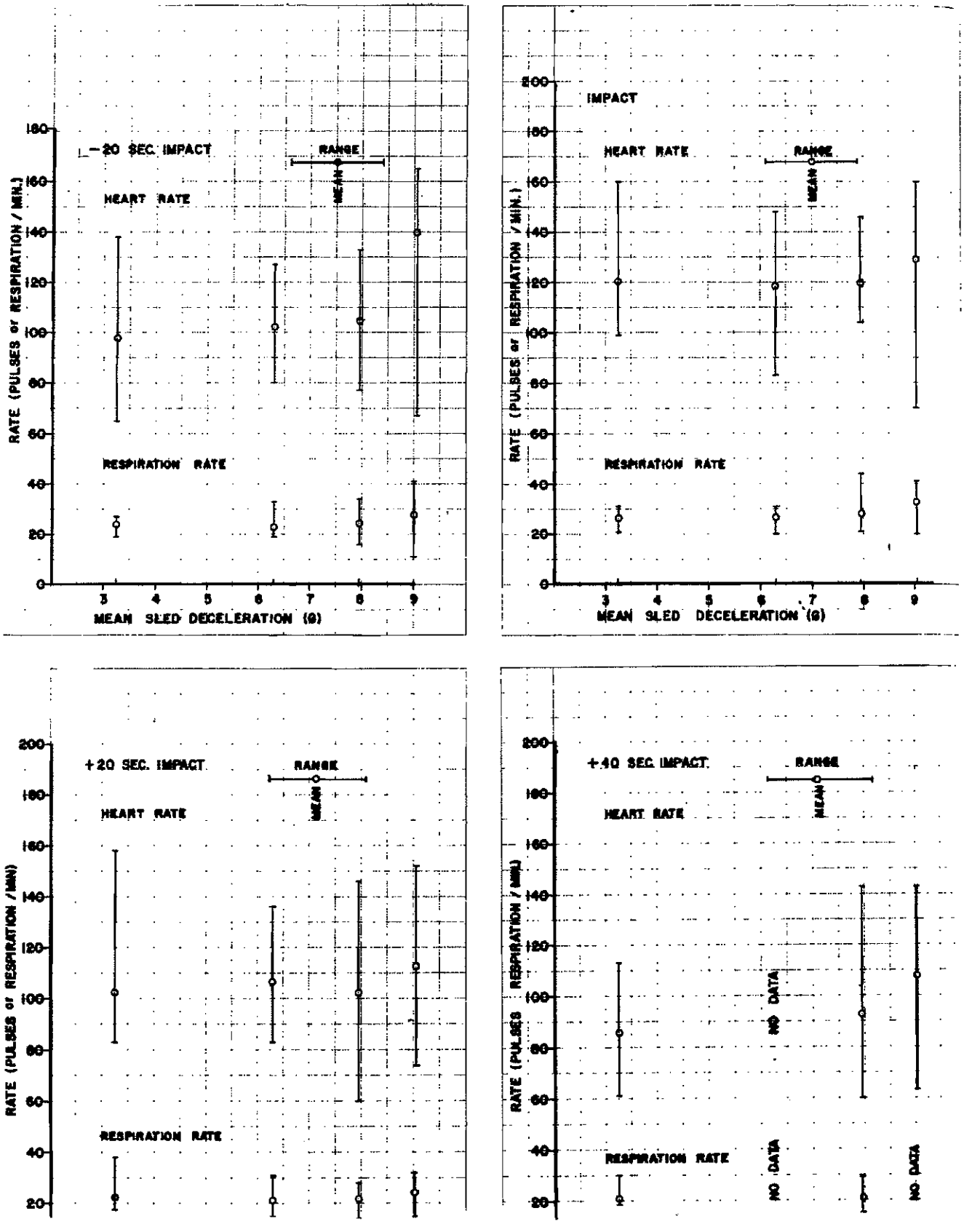
RESULTS

Typical deceleration records are shown for each series of runs and represented by Run 2438 for the programmed 4 G series, 2455 for 6 G, 2510 for 8 G, and 2532 for the 10 G series (Figures 5, 6, 7). These typical records are included as the best way of describing the entire deceleration pattern since the pattern is complex and idealization would make any description useless. The records also indicate typical deceleration times.

Each record has an identifying number block, and within it is a dashed line. This line represents one inch on the actual record. Each record has 10 traces of data numbered 1–10 from top to bottom. Each test required two separate records identified by Graph I and Graph II. Calibration data for this representative set are given in Table 3.

Complete physical data are given in Table 4A-D, where:

FIGURE 9. Average Heart and Respiration Rates during each run Series.



Sled Program Velocity is the velocity of the seat-sled system as it enters the brake, determined by measuring the time of travel over a prescribed 1-foot distance with Berkley Counters.

Stopping Distance is distance required in the brake to stop the sled-seat system.

Sled Acceleration Peak G is the maximum G attained during deceleration determined from computer program and checked by inspection of traces.

Sled Acceleration Onset is the linear onset characteristic of G determined by the computer program.

Subject Chest Peak G is the maximum value of G attained from the vector sum of accelerations from the triaxial chest pack by computer program.

Subject Chest Onset is the linear characteristic of the vector sum of accelerations from the chest pack by computer program.

Subject Head Peak G is the maximum value of G attained from accelerations from the triaxial head pack by computer program.

Subject Head Onset is the linear characteristic of the vector sum of accelerations from the head pack by computer program.

Subject Motion Chest is the flexion of the spine laterally so that the left shoulder contacts the left 30° side plate. N indicates no contact, Y indicates contact, by inspection of high-speed film.

Subject Motion Head is the flexion of the spine laterally to such a degree that both the left shoulder and head contact the left 30° side plate. N indicates no contact, Y indicates contact, by inspection of high-speed film.

Complete physiological data are given in Table 5A-D, where:

Heart Rate is given from pre- and post-run physical examination and at —20 seconds, impact, +20 seconds, and +40 seconds during the experiment.

Blood Pressure is given from pre- and post-run physical examination and at —20 seconds, impact, +20 seconds, and +40 seconds during the experiment.

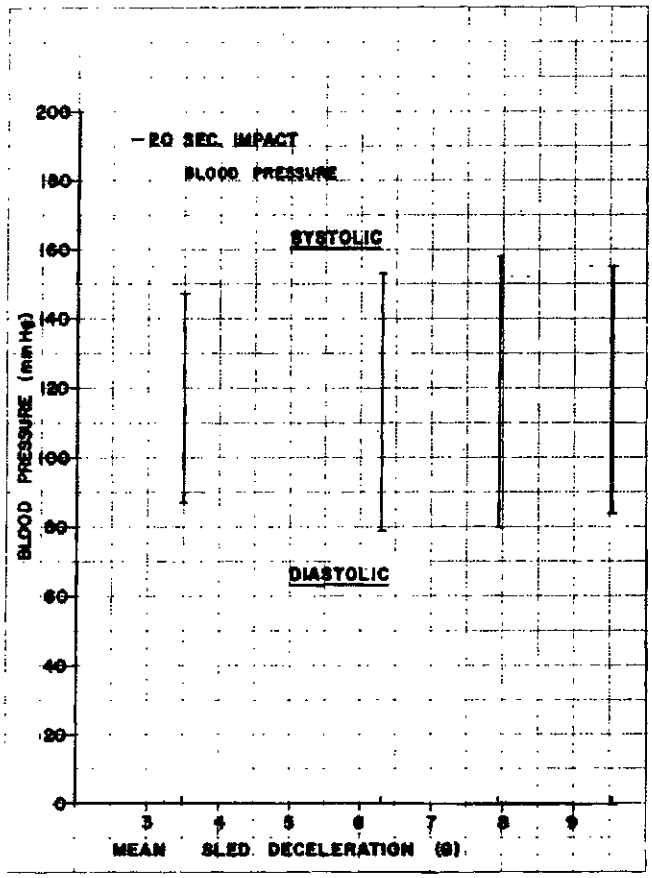
Respiration Rate is given from —20 seconds, impact, +20 seconds, and +40 seconds during the experiment.

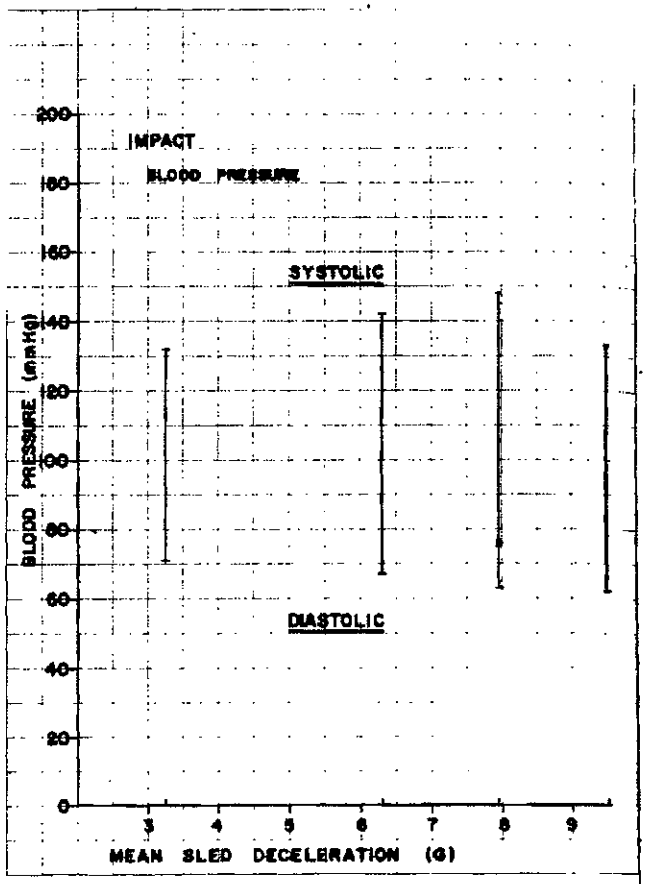
Condition of the Subject After Test is taken from the subject's 72-hour subjective report and medical examiner's post-run physical examination. Zero (0) indicates no response of pain or discomfort, numbers 1–27 indicate positive responses to pain or discomfort (Table 6).

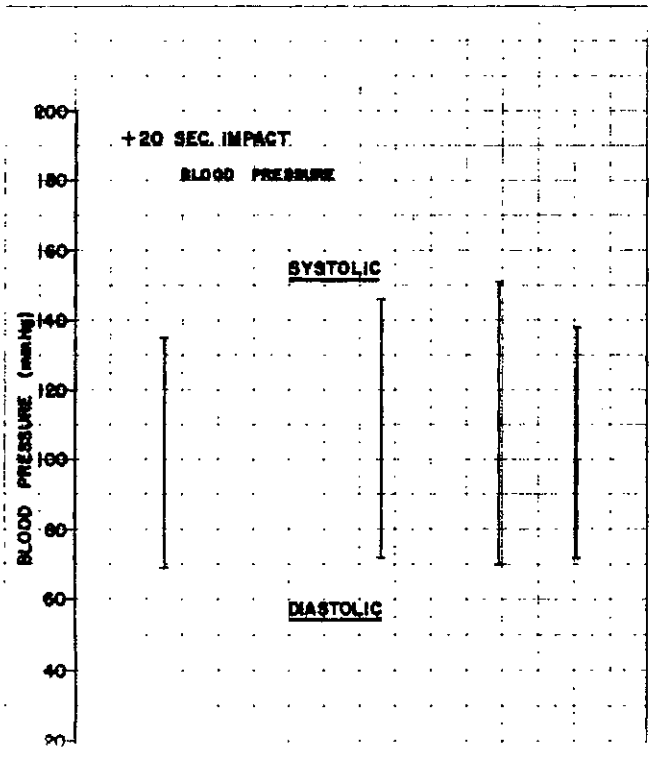
DISCUSSION

The data indicate that there were no important differences, in general, between the pre- and post-run physiological data (Figures 8, 9, 10). During the experiment itself, blood pressures and heart rates exceeded pub-

FIGURE 10. Average Systolic and Diastolic Blood Pressures during Each Run Series.







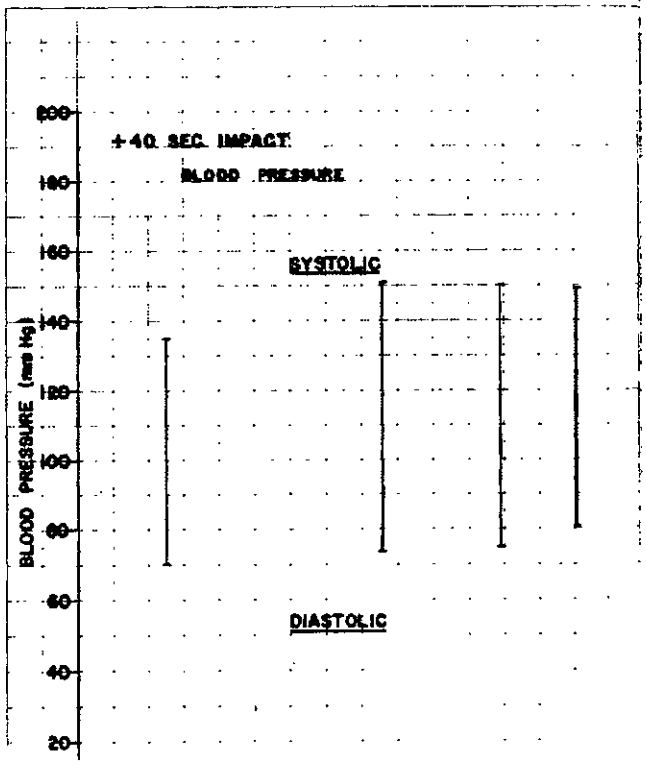


TABLE 4A
PHYSICAL DATA
4 G

		Sled						Subject					
		Program				Acceleration		Chest		Head		Subject Motion	
Run	Subject	Velocity ft/sec	Velocity m/sec	Stopping Distance ft	Stopping Distance meters	Peak G (G)	Onset (G/sec)	Peak G (G)	Onset (G/sec)	Peak G (G)	Onset (G/sec)	Chest	Head
2432	WNA	13.5	(4.11)	2.46	(.749)	2.93	191	10.02	181	3.74	51	N	N
2433	JLA	14.8	(4.51)	2.46	(.749)	2.98	159	4.70	131	3.04	65	N	N
2434	WCT	14.4	(4.39)	2.46	(.749)	3.41	151	10.14	211	3.34	52	N	N
2435	JPW	14.0	(4.27)	2.46	(.749)	3.44	150	11.01	246	4.20	54	N	N
2436	JWP	13.9	(4.24)	2.46	(.749)	3.14	223	8.94	174	3.40	30	—	—
2438	CGO	14.2	(4.33)	2.42	(.738)	3.33	146	12.20	155	4.30	46	Y	N
2439	CAR	14.2	(4.33)	2.44	(.744)	3.20	153	7.56	90	3.30	20	N	N
2440	ERS	13.7	(4.18)	2.44	(.744)	3.34	78	9.08	50	3.97	46	N	N
2441	WHT	14.2	(4.33)	2.44	(.744)	3.21	93	6.69	141	4.30	37	Y	N
2442	SMcD	14.8	(4.51)	2.42	(.738)	3.26	90	20.72	487	6.20	36	Y	N
2443	FJC	14.1	(4.29)	2.44	(.744)	3.50	130	13.89	185	5.41	60	N	N
2444	GWC	14.5	(4.42)	2.44	(.744)	3.22	95	9.52	135	2.33	30	N	N

TABLE 4B
PHYSICAL DATA
6 G

		Sled				Subject							
		Program				Acceleration		Chest		Head		Subject Motion	
Run	Subject	Velocity ft/sec	Velocity m/sec	Stopping Distance ft	Stopping Distance meters	Peak G (G)	Onset (G/sec)	Peak G (G)	Onset (G/sec)	Peak G (G)	Onset (G/sec)	Chest	Head
2453	JOE	15.7	(4.78)	1.33	(.405)	5.79	341	21.38	824	6.59	275	N	N
2454	PF	15.0	(4.57)	1.21	(.369)	7.06	315	30.78	436	46.40	115.7	Y	Y
2455	DNA	15.1	(4.60)	1.29	(.393)	6.38	427	21.23	911	10.67	319	N	N
2456	KDH	14.4	(4.39)	1.29	(.393)	5.48	318	14.28	369	9.51	115	N	N
2457	JDT	14.65	(4.45)	1.25	(.381)	6.64	290	19.82	674	12.40	170	Y	N
2458	JRB	15.6	(4.75)	1.27	(.387)	6.94	336	27.75	405	17.37	175	Y	Y
2459	TRT	15.2	(4.63)	1.29	(.393)	6.25	258	25.22	522	8.82	129	N	N
2460	WCC	14.6	(4.45)	1.25	(.381)	6.64	384	23.34	287	11.32	122	Y	N
2461	YSF	14.4	(4.39)	1.25	(.381)	6.65	265	17.30	233	11.19	271	N	N
2462	JWR	14.8	(4.51)	1.29	(.393)	6.40	431	22.05	1,769	8.51	207	N	N
2476	RJB	15.1	(4.60)	1.35	(.411)	5.77	182	20.14	383	9.81	88	Y	N
2477	CAC	14.8	(4.51)	1.33	(.405)	6.25	252	20.76	392	9.59	95	Y	N
2478	CRM	14.9	(4.54)	1.40	(.427)	5.82	142	14.99	101	9.20	88	N	N
2479	JHS	15.6	(4.75)	1.16	(.354)	6.13	217	21.73	328	15.11	222	Y	N
2480	CWH	15.3	(4.66)	1.40	(.427)	6.43	160	19.34	362	9.66	149	Y	N
2481	GOS	15.2	(4.63)	1.21	(.369)	5.74	182	17.84	252	9.21	130	Y	N
2482	RR	15.9	(4.85)	1.33	(.405)	6.70	317	25.68	305	11.02	115	Y	N
2483	CR	15.6	(4.75)	1.25	(.381)	6.31	185.3	25.41	290	32.05	762	Y	Y

TABLE 4C
PHYSICAL DATA
8 G

Run	Subject	Sled						Subject					
		Program				Acceleration		Chest		Head		Subject Motion	
		Velocity		Stopping Distance		Peak G	Onset	Peak G	Onset	Peak G	Onset		
		ft/sec	m/sec	ft	meters	(G)	(G/sec)	(G)	(G/sec)	(G)	(G/sec)	Chest	Head
2491	JWR	15.4	(4.69)	1.10	(.335)	7.85	347	25.26	1,110	8.10	195	Y	N
2492	SMcD	15.8	(4.82)	1.06	(.323)	8.83	348	41.31	810	—	—	Y	Y
2493	GJV	—	—	1.15	(.351)	7.41	345	26.90	593	7.99	145	N	N
2494	WCT	15.2	(4.63)	1.10	(.335)	7.95	333	31.77	1,410	22.72	424	N	N
2495	JWP	14.4	(4.39)	1.08	(.329)	7.52	341	26.96	770	20.25	739	Y	Y
2496	RJB	14.8	(4.51)	1.12	(.341)	7.37	298	22.21	458	8.54	98	Y	N
2497	JPW	14.9	(4.54)	1.15	(.351)	8.03	362	22.95	500	7.05	129	Y	N
2498	WG	16.1	(4.91)	1.06	(.323)	8.48	423	50.82	1,471	—	—	Y	Y
2499	GVA	15.9	(4.85)	1.10	(.335)	7.77	402	25.08	690	9.92	154	Y	Y
2500	RWD	15.8	(4.82)	1.08	(.329)	—	—	8.98	109	—	—	Y	N
2503	JLA	15.0	(4.57)	1.06	(.323)	7.55	343	18.87	281	7.36	147	Y	N
2504	GAG	14.9	(4.54)	1.10	(.335)	7.61	300	10.11	526	22.06	536	Y	Y
2505	CAC	15.4	(4.69)	1.06	(.323)	8.50	338	38.97	565	—	—	Y	Y
2506	JRB	15.8	(4.82)	1.10	(.335)	8.16	380	40.33	726	27.60	164	Y	Y
2507	CWH	15.3	(4.66)	1.08	(.329)	8.09	292	21.06	370	9.92	256	Y	N
2508	CRM	14.5	(4.42)	1.10	(.335)	7.49	309	9.89	666	8.33	111	Y	N
2509	JDT	14.9	(4.54)	1.08	(.329)	8.23	339	17.29	837	8.54	137	Y	N
2510	DNA	15.8	(4.82)	1.10	(.335)	7.55	337	24.13	889	10.65	151	Y	N
2511	JAS	15.4	(4.69)	1.06	(.323)	8.28	400	39.00	329	12.49	396	Y	N
2512	RR	15.9	(4.85)	1.10	(.335)	8.43	411	25.08	312	25.65	297	Y	Y

TABLE 4D
PHYSICAL DATA
10 G

		Sled						Subject					
		Program				Acceleration		Chest		Head		Subject Motion	
		Velocity		Stopping Distance									
Run	Subject	ft/sec	m/sec	ft	meters	Peak G (G)	Onset (G/sec)	Peak G (G)	Onset (G/sec)	Peak G (G)	Onset (G/sec)	Chest	Head
2526	JHS	14.35	(4.36)	1.22	(.372)	9.70	359	24.50	266	11.12	184	Y	N
2527	JOE	14.4	(4.39)	.96	(.292)	8.90	284	13.90	209	8.33	103	Y	N
2528	JLP	15.1	(4.60)	.96	(.292)	9.95	300	19.90	265	14.38	162	Y	Y
2529	GAR	14.4	(4.39)	.96	(.292)	9.32	312	30.38	879	22.16	394	Y	Y
2530	ERS	14.8	(4.51)	.96	(.292)	8.48	271	14.47	215	22.04	321	Y	N
2531	CAR	14.5	(4.42)	.96	(.292)	9.06	311	17.70	196	9.34	143	Y	N
2532	TRT	15.2	(4.63)	.94	(.287)	9.24	379	23.15	588	16.10	322	Y	N
2533	WHT	14.5	(4.42)	.99	(.302)	8.88	315	16.44	285	9.69	160	Y	N
2534	CR	14.9	(4.54)	.98	(.299)	8.82	297	16.09	281	11.59	239	Y	N
2535	JNP	15.7	(4.78)	1.04	(.317)	9.16	322	24.13	420	9.41	150	Y	N
2537	GAG	14.4	(4.39)	.98	(.299)	8.53	316	17.10	488	16.48	476	Y	Y
2538	GWC	15.1	(4.60)	.98	(.299)	9.44	355	21.77	345	—	—	Y	Y
2539	CRM	14.7	(4.48)	.94	(.287)	9.02	338	18.02	358	12.78	224	Y	N
2540	JWP	14.3	(4.36)	.96	(.292)	8.83	311	17.05	333	20.92	647	Y	N
2541	JPW	15.8	(4.82)	.99	(.302)	8.83	291	18.14	272	19.97	693	Y	Y
2542	YSF	13.7	(4.18)	.99	(.302)	9.14	319	16.10	499	13.56	177	Y	N
2543	WCC	14.5	(4.42)	.99	(.302)	8.97	336	21.20	225	16.64	455	Y	Y
2544	WG	16.0	(4.88)	.99	(.302)	8.84	356	33.31	390	31.61	142	Y	Y
2545	FJC	15.3	(4.66)	1.02	(.311)	8.92	357	22.90	470	13.30	205	Y	Y
2546	GOS	15.4	(4.69)	1.04	(.317)	8.94	330	20.91	171	25.19	333	Y	Y

TABLE 5A
PHYSIOLOGICAL DATA
4 G SERIES

		Heart Rate (Beats/min)						Blood Pressure (mm Hg)						Respiration Rate (resp/min)				
		Physical Examination		Experimental				Physical Examination	Experimental					Experimental				Condition of Subject
Run	Subject	Pre	Post	−20	Impact	+20	+40	Pre	Post	−20	Impact	+20	+40	−20	Impact	+20	+40	After Test
2432	WNA	76	80	93	113	89	78	122/80	128/84	150/100	140/70	140/90	—	25	32	21	17	0
2433	JLA	72	76	77	101	83	66	108/64	108/70	—	110/70	110/70	—	25	22	20	21	0
2434	WCT	96	92	94	113	99	98	114/80	102/70	—	100/70	—	—	25	30	27	17	0
2435	JPW	92	82	82	99	83	79	118/82	124/82	—	110/80	110/70	110/70	19	27	15	15	0
2436	JWP	80	76	86	109	95	78	122/76	112/70	120/80	130/60	120/60	110/70	22	23	19	30	0
2438	CGO	108	112	113	126	112	112	122/78	126/72	155/80	130/70	120/70	130/80	20	30	20	16	0
2439	CAR	88	84	116	146	114	110	118/88	112/82	150/75	200/80	150/60	150/60	25	56	18	27	0
2440	ERS	100	96	138	160	158	—	118/82	124/86	170/90	—	135/70	—	25	24	22	—	0
2441	WHT	80	88	104	134	115	92	106/68	102/70	155/60	130/60	—	—	27	31	23	18	0
2442	SMcD	84	68	65	100	95	74	104/72	136/80	140/65	150/60	170/60	170/60	20	21	20	27	0
2443	FJC	92	104	114	132	118	94	122/76	124/78	150/80	130/80	140/80	140/80	25	26	24	21	0
2444	GWC	88	80	89	114	91	61	120/78	124/74	140/80	130/80	150/60	140/80	22	22	38	20	0

TABLE 5B
PHYSIOLOGICAL DATA
6 G SERIES

		Heart Rate (Beats/min)						Blood Pressure (mm Hg)						Respiration Rate (resp/min)				
		Physical Examination		Experimental				Physical Examination		Experimental				Experimental				Condition of Subject
Run	Subject	Pre	Post	−20	Impact	+20	+40	Pre	Post	−20	Impact	+20	+40	−20	Impact	+20	+40	After Test
2453	JOE	84	88	106	115	94	97	124/92	120/78	160/100	—	—	—	19	23	20	12	1
2454	PF	88	88	80	115	103	68	124/66	124/76	155/85	175/60	175/60	150/70	22	22	19	20	2
2455	DNA	84	72	99	119	106	—	116/76	122/76	140/90	140/70	150/80	—	23	21	19	—	3
2456	KDH	88	80	113	148	124	118	130/86	126/80	130/90	160/90	170/90	—	22	27	21	21	0
2457	JDT	92	88	84	102	104	—	126/86	110/80	—	145/70	139/85	—	21	25	16	—	4
2458	JRB	76	72	134	148	132	—	104/72	108/70	120/80	120/80	130/70	—	33	31	31	—	0
2459	TRT	76	80	—	83	83	—	106/68	104/64	—	110/60	120/70	—	—	29	23	—	5
2460	WCC	84	76	103	117	97	77	108/66	104/70	125/80	110/60	—	—	24	23	23	23	0
2461	YSF	108	84	104	111	94	88	146/92	128/88	130/80	140/70	150/70	—	27	29	21	27	0
2462	JWR	72	68	95	94	88	65	118/76	112/66	140/80	140/60	130/70	130/70	28	23	19	21	6
2476	RJB	84	88	131	159	136	129	106/74	104/70	160/60	—	140/80	—	25	35	21	22	7
2477	CAC	84	80	116	141	111	81	116/74	108/78	190/60	—	—	200/60	28	29	18	18	0
2478	CRM	76	72	98	130	118	93	126/76	122/80	170/90	120/60	160/80	140/90	29	32	23	28	0
2479	JHS	76	68	92	108	102	—	118/74	110/70	140/60	140/60	140/60	—	23	20	17	—	0
2480	CWH	88	80	106	122	102	89	104/72	114/68	160/70	160/50	130/60	150/70	28	27	21	22	8
2481	GOS	72	88	122	137	131	114	124/84	116/84	200/80	180/80	170/80	180/90	23	27	26	25	0
2482	RR	64	76	89	89	131	70	96/64	98/60	140/85	130/60	120/60	110/60	27	24	20	—	0
2483	CR	68	76	85	115	93	64	120/76	156/88	180/80	170/70	170/70	150/80	21	34	22	21	0

TABLE 5C
PHYSIOLOGICAL DATA
8 G SERIES

		Heart Rate (Beats/min)						Blood Pressure (mm Hg)						Respiration Rate (resp/min)				
		Physical Examination		Experimental				Physical Examination		Experimental				Experimental				Condition of Subject
Run	Subject	Pre	Post	−20	Impact	+20	+40	Pre	Post	−20	Impact	+20	+40	−20	Impact	+20	+40	After Test
2491	JWR	72	84	94	113	98	—	116/80	118/82	170/90	200/60	170/70	—	22	23	28	—	9
2492	SMcD	72	84	88	95	60	60	112/76	120/84	140/70	140/60	—	—	23	30	—	—	10
2493	GJV	88	84	104	148	119	101	118/72	128/82	160/80	150/70	170/80	160/80	20	18	23	50	0
2494	WCT	76	84	98	110	101	92	104/72	136/84	150/80	170/70	160/60	130/70	34	44	18	21	0
2495	JWP	92	104	—	111	97	90	104/80	124/86	150/70	—	140/70	140/70	—	30	25	25	11
2496	RJB	76	84	133	156	146	143	106/68	124/76	180/100	130/70	160/80	—	29	22	20	50	0
2497	JPW	72	80	77	94	84	75	118/82	122/80	135/90	130/70	130/70	—	17	22	17	25	0
2498	WG	80	72	98	110	101	92	118/76	116/72	170/90	160/70	150/70	160/80	34	44	18	21	12
2499	GVA	76	70	92	104	114	86	102/72	108/80	180/80	160/50	170/50	160/60	28	20	14	17	0
2500	RWD	76	90	121	140	124	112	102/68	108/80	200/80	130/60	160/80	150/80	27	31	25	19	13
2503	JLA	72	66	100	118	98	77	104/62	118/62	140/90	140/50	130/70	135/80	21	22	23	—	14
2504	GAF	88	88	99	112	84	71	116/82	114/68	150/90	130/60	140/80	130/80	22	23	22	16	0
2505	CAC	88	88	128	134	112	80	106/74	107/64	160/60	—	160/60	150/80	22	28	17	16	0
2506	JRB	92	76	131	146	122	106	110/66	104/70	130/60	160/50	120/70	—	29	32	28	29	15
2507	CWH	108	100	110	106	104	92	122/66	114/72	180/60	130/60	150/60	150/60	23	23	23	24	16
2508	CRM	76	84	109	137	128	103	116/80	104/78	200/90	150/70	180/80	180/80	27	31	26	23	0
2509	JDT	84	80	84	103	95	—	120/86	124/88	130/90	180/80	190/80	—	24	23	24	—	0
2510	DNA	88	84	99	120	92	63	108/70	104/78	120/70	170/60	130/70	—	16	38	21	16	0
2511	JAS	88	82	118	144	128	120	112/74	106/80	150/70	140/60	140/60	—	19	21	19	15	17
2512	RR	84	82	94	94	80	—	114/74	104/78	120/80	100/60	120/70	—	25	36	18	—	18

TABLE 5D
PHYSIOLOGICAL DATA
10 G SERIES

		Heart Rate (Beats/min)						Blood Pressure (mm Hg)						Respiration Rate (resp/min)				
		Physical Examination		Experimental				Physical Examination		Experimental				Experimental				Condition of Subject
Run	Subject	Pre	Post	−20	Impact	+20	+40	Pre	Post	−20	Impact	+20	+40	−20	Impact	+20	+40	After Test
2526	JHS	80	92	—	152	146	124	120/82	120/84	150/80	160/80	150/70	160/80	—	29	24	14	0
2527	JOE	88	92	126	118	97	89	128/86	124/76	200/130	—	180/100	160/100	30	22	21	23	19
2528	JLP	86	92	104	151	124	—	120/80	142/90	120/80	200/50	160/60	200/50	28	45	25	—	20
2529	GAR	80	92	165	89	88	—	116/72	106/70	150/90	155/60	—	135/50	23	20	15	—	21
2530	ERS	92	96	143	152	152	143	118/84	118/84	140/80	120/70	130/80	130/80	31	25	20	30	22
2531	CAR	64	84	120	155	143	134	118/78	116/74	180/90	130/50	160/60	150/70	30	34	25	42	0
2532	TRT	72	72	67	70	77	—	110/66	106/64	130/80	110/50	130/70	—	27	30	22	—	23
2533	WHT	92	92	132	155	119	116	108/82	112/78	170/80	100/60	—	—	19	26	23	20	0
2534	CR	76	76	87	124	74	63	128/92	132/80	150/100	140/70	—	140/75	31	33	16	23	0
2535	JNP	96	80	104	140	121	69	112/80	126/72	150/160	140/70	—	150/80	22	30	23	27	24
2537	GAG	80	84	107	113	92	85	112/72	120/70	190/60	170/70	170/70	—	27	32	32	22	0
2538	GWS	96	—	111	122	101	—	182/72	—	130/70	115/70	150/80	—	25	29	21	—	25
2539	CRM	88	96	142	156	145	134	114/76	112/76	190/80	140/70	160/80	170/80	29	31	27	25	0
2540	JWP	88	92	98	106	83	—	122/76	118/76	170/90	110/40	120/80	—	27	32	23	—	26
2541	JPW	92	92	99	116	94	90	110/74	106/72	140/80	130/60	120/60	—	11	35	23	—	27
2542	YSF	84	92	112	150	94	—	140/82	128/80	—	130/60	120/70	—	36	53	31	—	28
2543	WCC	80	96	117	127	113	—	110/74	106/68	110/60	110/60	110/70	—	31	22	27	—	0
2544	WG	84	84	92	108	101	—	106/76	112/80	160/90	160/70	160/70	150/80	23	25	27	—	0
2545	FJC	108	124	146	160	152	—	132/86	120/82	160/70	150/50	160/60	—	41	41	29	—	0
2546	GOS	120	128	140	152	137	137	118/84	136/88	190/80	120/60	160/70	—	25	35	27	16	29

CONDITION OF SUBJECT AFTER TEST
TABLE 6

Reference No.	*Subject*	*Remarks*
1	JOE	Subject Reports – "Several minutes after the ride a very mild pain appeared in my lower spine. This lasted only a few minutes." Medical Examiner Reports – Post-run examination normal.
2	PF	Subject Reports – "I experienced at the time of impact a heavy blow to the head and shoulder, causing a moderate headache which lasted for about 5 minutes. At this time there was no noticeable pain on any other part of the body. Post run: I developed a stiffness in my neck on the right side, the side opposite impact. The stiffness persisted for 3 days, also a soreness in the hips where the lap belt had been, about 48 hrs post run." Medical Examiner Reports – Post-run examination normal.
3	DNA	Subject Reports – "No pain at impact. The following morning when I got up the right side of my neck was sore. This lasted for about 24 hrs." Medical Examiner Reports – Post-run examination normal.
4	JDT	Subject Reports – "The next morning I had mild soreness and stiffness in my neck. It was hardly noticeable the following morning. I felt good and relaxed after the ride." Medical Examiner Reports – Post-run examination normal.
5	TRT	Subject Reports – "At impact my trunk (head, shoulders especially) pitched to the left. Increased pressure on my lap belt, especially on the right side. I also noticed some stiffness immediately post impact. Pain occurred across both hip bones, especially the right hip bone. Some stiffness in my cervical area which dissipated immediately post impact plus 15 sec." Medical Examiner Reports – Post-run examination – strap pressure right hip, examination normal.
6	JWR	Subject Reports – "At impact I felt a little pain from the lap strap on the crest of my right hip. The pain subsided before I left the sled. No bruise." Medical Examiner Reports – Post-run examination normal.
7	RJB	Subject Reports – "At impact I swung to the left probably thirty-five (35) degrees. The only sensation was tension on the anal sphincter apparently due to a slight slide in the sitting position at impact." Medical Examiner Reports – Post-run examination normal.
8	CWH	Subject Reports – "There was a slight burning sensation that lasted about a minute when I slid across the seat

TABLE 6 (continued)

Reference No.	*Subject*	*Remarks*
		under the seat belt." Medical Examiner Reports – Post-run examination normal.
9	JWR	Subject Reports – "At impact my body pitched to the left and then back to the original position. Again the pain over each hip bone which quickly subsided." Medical Examiner Reports – Post-run examination normal.
10	SMcD	Subject Reports – "I was in good condition, except I had been partying that night but not after 12 o'clock. I was not afraid because I had ridden this ride before. The strapping was even and tight, no pressure points. My body and back were firmly in the seat, my hands in my lap. During acceleration I began to feel faint. Upon impact I blacked out. To me it only seemed like a few seconds that I was out. However, I later found out it was longer than I thought. When I recovered things were blurred and I was confused for a moment. I had no difficulty with breathing. I was all right by this time, I felt normal. No pain. I felt no pain during post-impact. I felt sort of tired and nervous because of what had happened and the possibility that I may be put out of sled status. I have no idea of how many G's I pulled." Medical Examiner Reports – Post-run examination – "Patient was loose and head hit side cushioning rather hard and immediate loss of consciousness for 2 minutes. Patient revived and confessed to being 'hung over.' Examination essentially normal."
11	JWP	Subject Reports – "After impact I had a headache which lasted for about two hours." Medical Examiner Reports – Post-run examination – "Head moved and hit shoulder, mild headache. No complaints however. Examination within normal limits."
12	WG	Subject Reports – "I experienced double vision for about four (4) seconds after impact. No faintness or dizziness. I had pain at impact on the left of my head. I think it was due to my head striking the front head rest. About 6 hours post-run I had a stiff neck on the right side. I think that was only a sore muscle." Medical Examiner Reports – Post-run examination – "Stunned momentarily but quickly regained composure. Post-run examination is normal."
13	RWD	Subject Reports – "No pain at impact. Approximately eight hours after impact the right side of my neck felt stiff; however, the next morning I had no pain." Medical Examiner Reports – Post-run examination – "Examination within normal limits."

TABLE 6 (continued)

Reference No.	*Subject*	*Remarks*
14	JLA	Subject Reports – "I experienced a very mild amount of pain over the hip regions where the lap belt was secured. I experienced no undue discomfort or difficulty in the post-run period whatsoever." Medical Examiner Reports – Post-run examination – "No complaints except very mild strap burns."
15	JRB	Subject Reports – "Upon impact my body from the waist up moved noticeably to the left. My head hit the board. The force was taken evenly as to be expected. I noticed more burning on my ilium than last time. This was caused, I think, because I was not strapped in quite as tight as last time. The duration of impact seemed shorter than last time. I had no pain. My head did not hit the board hard enough. It was just a slight touch." Medical Examiner Reports – Post-run examination OK.
16	CWH	Subject Reports – "On acceleration I noticed a marked lateral movement to the right. On impact I felt my entire body shift laterally to the left. I felt some pain as the lap belt slid over my hips. My trunk tossed to quite an extent to the left with my head going far over on my shoulder. I noticed no symptoms of any kind immediately after the ride. There was some stinging and some small hematomas over my hips where the belt had been. At 24 hours after the ride there was considerable soreness in the right side of my neck that continued on down behind the right scapula. These are the only ill effects that I noticed after the ride. After the run I felt relaxed and glad to have it over with." Medical Examiner Reports – Post-run examination – "No complaints. Examination OK."
17	JHS	Subject Reports – "At impact I experienced a violent movement to the left being the direction of movement at impact. My arm seemed to take most of the impact and for a few seconds it was numb throughout, but returned to normal soon after. I felt no other abnormal signs other than the usual tired feeling that seems to follow most rides. I had no difficulty in breathing, nor did I feel any dizziness." Medical Examiner Reports – Post-run examination – "No complaints. Examination within normal limits."
18	RR	Subject Reports – "At impact my head swung to the side and barely hit the side panel. All of the pressure was taken at the lap belt, but no pain was noticeable. I was not disoriented. I did not experience blurred or double vision. No difficulty with breathing was experienced nor

TABLE 6 (continued)

Reference No.	*Subject*	*Remarks*
		faintness or dizziness. No pain at impact. I experienced a three hour post-run pain around the right side of neck and back. It lasted for about 48 hours." Medical Examiner Reports – Post-run examination – "No complaints."
19	JOE	Subject Reports – "Upon impact my body tilted to the left somewhat. The force was taken mostly on my left arm and shoulder. My head didn't quite touch the padding to my left. No unusual conditions were noted except a mild momentary pain under my chin across my neck." Medical Examiner Reports – Post-run examination – "Examination OK."
20	JLP	Subject Reports – "We were advised to lean a little into the end of the track just before acceleration. My body felt rigid and prepared. During acceleration I let myself become too relaxed, putting too much attention on keeping my arms from being thrown to any one side and not giving my neck action the proper attention. Duration seemed very short. On impact I believe I shoved my hands forward. I did feel myself take a great lean to the left, in turn almost hitting my head against the rest. No pain was felt along the buttocks or hip bone. After impact, I did feel slightly stunned, however, vision and breathing seemed normal. I felt stunned because I had no idea the run would be so different from the vision I had imagined. Moments after impact I felt as if I had just been hit in the head, but there was no pain or dizziness; it was as if time had stopped for a matter of seconds. The stunned feeling only lasted a few seconds. I felt no pain after impact or had any trouble breathing. There was no faintness or dizziness. Right after the run I could feel no changes in normal physical condition. Hours post-run there was a little stiffness in the right side of my neck. The stiffness lasted for the following three days. Cause was linked with the sudden jerk my neck took on impact. The pain was located from the midway neck line to the right shoulder. Immediately following the ride I felt greatly relieved." Medical Examiner Reports – Post-run examination – "No complaints, examination OK."
21	GAR	Subject Reports – "I rocked to the left right on impact, but felt no pain from impact. I had no actual pain, but as I was leaving the seat, I had a dull ache in the back of my head, but subsided by the time I got to the examination room." Medical Examiner Reports – Post-run examination – "Examination OK."
22	ERS	Subject Reports – "At impact my trunk moved to the left side, with my left elbow going into the side. I noticed

TABLE 6 (continued)

Reference No.	*Subject*	*Remarks*
		some pressure in my eyes after impact. I experienced blurred vision for about ten (10) seconds after impact. No pain at impact. Immediately post-impact I felt tired and relaxed." Medical Examiner Reports – Post-run examination – "Examination within normal limits."
23	TRT	Subject Reports – "At impact my trunk pitched to the left and my neck snapped. I noticed increased pressure in my head, producing a headache. I had some difficulty for just a few seconds in gaining my orientation. I had some difficulty in breathing immediately after impact, lasting just a short time. Slight dizziness followed associated with this temporary disorientation. I experienced pain, localized in my neck, trapezius muscles on the left. This lasted for three days and gradually dissipated with time. The headache also left me about 6 hours after the ride. Immediately post-impact I experienced relief and a sore neck." Medical Examiner Reports – Post-run examination – "Examination within normal limits."
24	JNP	Subject Reports – "I think the impact caused a slight sliding sensation. Although only my head moved, I felt like I was sliding. Duration was short. When it came time for eyeball movement, I couldn't hear the man yell out the commands to me. I don't know if it was my fault or not. I don't think I was disoriented." Medical Examiner Reports – Post-run examination – "Examination OK."
25	GWC	Subject Reports – "On impact my head hit the brace and I felt a sharp pain shoot across my forehead. It lasted just a split second then became real slight. I didn't become disoriented nor did I experience double vision. I had no trouble in breathing at any time. My headache was completely gone about one-half hour after the ride. The next morning I woke up with a stiff neck which went away the following night. Right after the ride I felt real tired." Medical Examiner Reports – Post-run examination – "Subject mildly hit head into lateral seat restraint. Felt sharp but mild to moderate parietal headache immediately after. Fading rapidly within 1–3 min. No physical signs of CNS or systemic injury. Vision continually clear."
26	JWP	Subject Reports – "On impact my head pulled to the left and my neck was sore for about three days. I also had a headache for about an hour." Medical Examiner Reports – Post-run examination – "Noticed 'popping' in (R) side of neck at impact. No pain or other symptoms associated. No evidence of injury. Asymptomatic."
27	JPW	Subject Reports – "Acceleration seemed short. I pitched way over to the left just barely missing the safety shield

TABLE 6 (continued)

Reference No.	*Subject*	*Remarks*
		with my head. I felt fine except for some rectal pain caused from the gluteal muscles separating on impact. This lasted for about 2 to 3 minutes then was gone. No double vision. No lightheadedness, dyspnea or confusion. About 2 hours post-impact I developed a slight headache. I don't know if it was from not eating for so long or from the sled ride. It disappeared after I went home and ate supper. Approximately 18 hours post-impact I noticed some stiffness and tenderness of the muscles on the right side of my neck and right trapezius muscle. At this writing the muscles are still a bit tender on left lateral extension." Medical Examiner Reports – Post-run examination – "Asymptomatic, no signs of injury."
28	YSF	Subject Reports – "I experienced no ill effects after the ride, no pain, dizziness, faintness, difficulty with my breathing, and no double vision. About a half an hour after the ride I had a dull headache in the back of my head which persisted for about 15 minutes then disappeared and didn't come back." Medical Examiner Reports – Post-run examination – "Completely asymptomatic. No signs of injury."

lished average normals momentarily, but without ill effects as attested to by the medical examiner during his post-run examination.

The acceleration data as recorded have certain limitations. The attachment of transducers to the living subject is difficult. In these studies both the chest and head accelerometer packs were solidly attached to the subject by straps over bony structures. The response of the attached transducers, in relation to the response of that particular portion of the subject, is sometimes questionable. In this case it can only be said that established practices have been followed and that errors in this study in this regard are common to such studies as reported in the past.

Until detailed investigations into human subject dynamic transducer mountings are accomplished, the data can only be used as they are.

Average physical response data from the subject's head and chest accelerometers have been plotted (Figure 11). Ratios of mean Chest/Sled and Head/Chest data are shown plotted versus mean sled decelartions (Figure 11). These ratios, of peak response to peak input, are often referred to as Dynamic Load Factors. In the case of these ratios the sled deceleration is input to the chest, lumping the seat, the lap belt, and the

pelvic regions as one mass for transmission; and the chest is input to the head with the neck musculature and vertebrae as a lumped mass for transmission.

The ratio of Head/Chest rises with increasing mean sled decelerations while the Chest/Sled ratio rises to a peak of 3.35 and then decreases rapidly to 1.78 at the maximum mean sled deceleration level of 9.02.

Patrick (1964) states that "the maximum Dynamic Load Factor is a function of the terminal or mean acceleration – the greater the acceleration the greater the maximum Dynamic Load Factor." Since no attempt was made to perform theoretical calculations on the conditions that existed in this series of tests, the decrease may be a result of the influence of the onset characteristic (G/sec or sometimes referred to as jerk) of the deceleration pulse. Patrick provides a graphical display of the effect of jerk on the Dynamic Load Factor based on a theoretical mathematical model (undamped) at 15 G and jerks up to 2,000 G/sec. His analysis shows a "knee" in the 200 to 400 jerk range. It is interesting to note that a decrease in the Dynamic Load Factor in these tests began at 7.9 mean G level and jerk ranges of 142 to 427 G/sec.

It should also be noted that the Subject Population Characteristics for each run series are essentially the same (Table 7). Consequently, it is reasonable to assume that the decrease in the Dynamic Load Factor was not caused by a change in subject characteristic.

Early in the experiments, subjects were instructed to maintain a relaxed or tensed (straining) attitude in the seat. It was immediately apparent from viewing the experiments, analysis of film, analysis of physiological data and subject responses that this was a practical impossibility. In general, all subjects were tense as evidenced by higher blood pressure, heart rates, and muscle tone. In all cases this was so except with subject PF in Run 2454, 6 G series and subject SMcD in Run 2492, 8 G series. Subject PF, a novice, having accumulated 81 G apparently accepted the instruction to relax and did so. He was one of the 16.7 per cent who impacted the left 30° side plate with his head. Recorded head accelerations were 46.40 G and the subject reported a positive response to pain or discomfort (Tables 4, 5, 6). Subject SMcD, unknown to the medical examiner, had not been well rested for his run. He too impacted his head violently to such an extent that he lost consciousness for approximately two minutes after impact, but recovered completely as reported by the medical examiner (Tables 4, 5, 6). Subject SMcD was one of 40 per cent that struck his head during the experiment (Figure 11). Resulting data indicate that tension or straining in the seat can minimize subject lateral motion during lateral impact, and that even at the 6 G level a completely relaxed subject would encounter difficulty in remaining upright and at the 10 G level a practical impossi-

FIGURE 11. Summary of Deceleration Data.

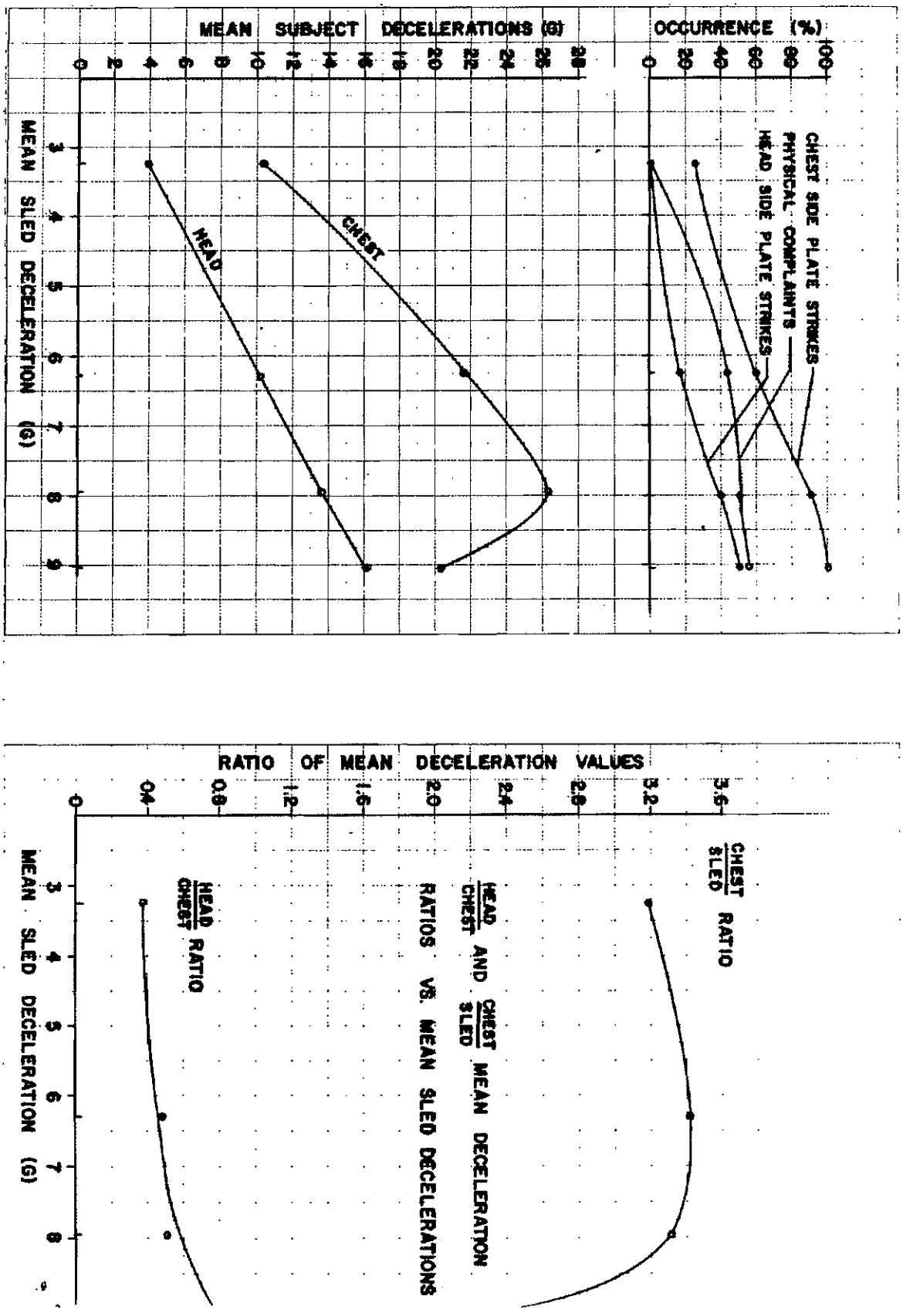


TABLE 7
SUBJECT POPULATION CHARACTERISTICS

Series		Age (yrs)	Weight lbs	Weight (kg)	Standing Height inches	Standing Height (cm)	Sitting Height inches	Sitting Height (cm)	Accumulated G
4 G	Avg.	27	166.4	(75.64)	68.1	(173)	35.2	(89.4)	308
	Median	24	165	(75.00)	68	(172.7)	35.7	(90.1)	225
	Range	41–20	191–124.5	(86.82–56.59)	71.3–65.4	(181.1–166.1)	36.2–32.4	(91.9–82.3)	536–111
6 G	Avg.	27	159.6	(72.55)	68.6	(174.2)	35.5	(90.2)	300
	Median	27	165	(75.00)	68.6	(174.2)	35.5	(90.2)	275
	Range	42–22	208.5–125	(94.77–56.82)	71.9–64.9	(182.1–164.8)	37.7–32.7	(95.8–83.1)	543–81
8 G	Avg.	29	150.6	(68.45)	67.7	(172)	35.2	(89.4)	347
	Median	29	155	(70.45)	68.5	(174)	35.6	(90.4)	275
	Range	41–22	191–119	(86.82–54.09)	71– 63.8	(180.3–160.1)	37.7–32.7	(95.8–83.1)	626–143
10 G	Avg.	27	172.7	(78.50)	68.1	(173)	35.3	(89.7)	389
	Median	25	172	(78.18)	68.1	(173)	35.6	(90.4)	412
	Range	42–22	202.8–141	(92.18–64.09)	71.4–63.8	(181.4–162.1)	37.2–32.4	(94.5–82.3)	565–165

bility. It is also possible that severe injury is possible at the 6 G level (Lissner et al, 1960). These two isolated occurrences indicate that the general population may not be so well protected as the more experienced sled subject.

CONCLUSIONS

Human tolerance to lateral impacts, while restrained with a lap belt restraining device, has been demonstrated in a limited sense:

a. No permanent physiological changes have been reported for the subjects under test while exposed to impacts of 9.02 G average and durations of approximately 0.1 seconds.

b. Minor physical complaints such as muscle stiffness occurred in approximately 50 per cent of the subjects after the average 6.25 G level.

c. Straining to remain in an upright seated position is effective with trained volunteers at impact levels of 3.25 average G and less and durations of approximately 0.3 seconds.

d. Some support to restrict lateral flexion would be most helpful.

e. Application of the techniques of mechanical vibration analysis could possibly be helpful in prediction of Dynamic Load Factors.

REFERENCES

DEMPSTER, WILFRED TAYLOR, "Space Requirements of the Seated Operator," WADC Technical Report 55-159, July 1955.

DUBOIS, EUGENE F., "Safety-Belts Are Not Dangerous," Cornell University Medical College, September 1952.

FAA Directive CAM 4b Airplane Airworthiness Transport Categories Paragraph 4b. 260, September 1963.

GODBY, R. O., et al, "Anthropometric Measurements of Human Sled Subjects," Technical Documentary Report No. ARL-TDR-63-13, April 1963.

LISSNER, H. R., LEBOW, M., AND EVANS, F. G., Experimental Studies on the Relation Between Acceleration and Intracranial Pressure Changes in Man," *Surg. Gynec. Obstet.* 111:329-38, September 1960.

PATRICK, LAWRENCE M., "Fundamental Aspects of Impacts to the Human Body," Presented at the Conference on the Effects of Shock and Vibration on the Human Body, University of Denver, March 13–14, 1964.

SEVERY, D. M., MATHEWSON, J. M., AND SIEGEL, A. W., "Auto Crash Studies," Report 59-10, University of California, Institute of Transportation and Traffic Engineering, January 1959.

STAPP, JOHN P., "Human Exposures to Linear Deceleration, II: The Forward Facing Position and the Development of a Crash Harness," AF Technical Report No. 5915, June 1949.

STAPP, JOHN P., "Human Tolerance to Deceleration," *Am. J. Surg.*, 93:734-740, 1957.

WEIS, E. B. JR., CLARKE, N. P., AND BRINKLEY, J. W., "Human Tolerance to Sev-

eral Impact Acceleration Orientations and Patterns," Presented at the Thirty-fourth Annual Meeting, Aerospace Medical Association, April 29–May 4, 1963.

APPENDIX

PROTOCOL OF 72 HOUR SUBJECTIVE REPORT

Subjective Reports will be *TYPED* in narrative form 72 hours post-run, and returned to *ARRB* not later than five (5) days following the ride.

SUBJECTIVE REPORT GUIDE

Name, Rank, AFSN
Run Number (B = Bopper, D = Daisy, H = Hyge)
Date of Run:
Statement of your health prior to run (recent cold, injuries, stiffness, etc.).
Apprehension (explain in detail).
Strapping (was it too tight or loose? Were there pressure points, etc.?).
Body Position (head, arms, hands, trunk, etc.).
Occurences during acceleration (subject's feelings regarding acceleration and duration).
Impact (explain in detail any movement, how and where force was taken, and duration of impact).
Disoriented (blurred or double vision, confusion, stunning, etc.).
Difficulty with breathing (pain on inspiration, expiration, difficulty taking deep breath, etc.).
Feeling of faintness or dizziness.
Pain (intensity, location, duration, changes, and type of pain).
Post-Impact (pain location, duration, possible causes – explain in detail).
General post-run feeling (tired, relaxed, nervous, etc.).
Other (estimate of G's pulled, opinion of ride, etc.).
Signature
Date

MEDICAL EXAMINER'S REPORT FORM

TEST DATA RECORD			TASK NUMBER
RUN NUMBER	DATE	FIRING TIME	PROJECT
FACILITIES			
SEAT ORIENTATION			
WEIGHT OF SLED		WEIGHT OF SEAT	
INSTRUMENTATION			
SUBJECT			
NAME	AGE	SEX	WEIGHT / HEIGHT
DAYS SINCE LAST RUN		LAST MEAL	
PERSONAL EQUIPMENT			
ANESTHESIA MGM		TOTAL MGM/LB	DURATION
MEDICATION			
RESTRAINTS			
OPERATIONAL RESULTS			
FIRING VELOCITY		BRAKING DISTANCE	
ACCELEROMETER READINGS			
DECELERATION (SLED)	HIP	CHEST	
DECELERATION TIME CURVE G/PER SEC (SLED)			
HIP	CHEST	OTHER	
DURATION OF G (O'MAX G)			

ARL HQ FORM FEB 61 0-9 (AROB)

MEDICAL EXAMINER'S REPORT FORM, Continued

CLINICAL TESTS	BEFORE	AFTER
X-RAY		
EKG		
EEG		
TEMPERATURE		
BLOOD PRESSURE		
PULSE		
RESPIRATION		
NEUROLOGICAL (REFLEXES)		
ORTHOPEDIC		
OPHTHALMOSCOPIC		
URINALYSIS		
OTHER		

STATUS OF SUBJECT:
BEFORE RUN
AFTER RUN
ATTENDING PERSONNEL
PROJECT
MEDICAL
VISITING
REMARKS