HUMAN SURVIVABILITY OF EXTREME IMPACTS IN FREE-FALL

63-15

FEDERAL AVIATION AGENCY
AVIATION MEDICAL SERVICE
AERO MEDICAL RESEARCH DIVISION
CIVIL AEROMEDICAL RESEARCH INSTITUTE
OKLAHOMA CITY, OKLAHOMA

AUGUST 1963

Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, Oklahoma. CARI Report 63-15. **HUMAN SURVIVABILITY OF EXTREME IMPACTS IN FREE-FALL** by Richard G. Snyder.

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2. Acceleration
3. Free-Fall
4. Impact Trauma
5. Crash Injury

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ABSTRACT

Human deceleration tolerances beyond the limits imposed by voluntary experimental methods were studied by means of intensive case histories of 137 individuals who have survived extremely abrupt impacts in accidental, suicidal, and homicidal free-falls. Fall distances ranged up to 275′ and calculated velocities up to 116 ft/sec (79 mph). Physical and biological data are presented on both sexes with an age range of 1½ to 91 years, and with impacts occurring in all body axis orientations. A detailed analysis of factors found to affect survivability in free-fall impacts is made. These cases, out of some 12,000 free-falls collected in the past two years, demonstrate that humans have survived impact forces considerably greater than those previously believed tolerable. Why some individuals are not fatally injured in certain cases of extreme impact remains unanswered, but evidence suggests that human tissues do not respond as expected in extremely abrupt impacts having time durations of less than .0006 seconds.

In the last decade considerable effort has been expended in seeking knowledge of human responses and limitations to deceleration, or impact, forces. Whether one is concerned with such problems as launch and re-entry phases of interplanetary space vehicles, occupant escape or crash survival in the supersonic transport, or the more mundane research associated with increasing human survival in aircraft and automotive accidents, the nagging question of human design specifications for this force field must be considered. Scientists such as Stapp (47-58), Swearingen (60-61), Beeding (2-5), Taylor (63), and others, have contributed immensely to our knowledge of deceleration effects upon the human organism. Such experimental work with human subjects to date has been limited to voluntary tests which have only accidentally exceeded the injury threshold limits. Forces beyond these levels are usually thought *a priori* to be so traumatic to render the individual unable to perform a function and cause lethal or irreparable injury. However, as data presented in this paper will show, some individuals apparently are able to tolerate impact forces many times above the accepted limits. Why?

The purpose of this study, which has now been in progress for over two years at the Civil Aeromedical Research Institute of the Federal Aviation Agency, is to document factual data concerning human survival of extreme impact forces, and attempt to identify more concisely the factors which determine an injury or a survival. An ultimate objective would be to apply such knowledge for prevention or modification of lethal or injurious levels in air crashes, as well as other abrupt impact situations involving very high impact forces. The investigation of extreme limits of human tolerance(s)

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See also, "Human Tolerances to Extreme Impacts in Free-fall", *Aerospace Medicine*, 34(8):695-709, 1963.

may provide clues or patterns which can open entirely new approaches to the protection of the body during high decelerative forces.

Not all deceleration research has utilized human subjects. Studies have employed such animals as mice (28, 29, 33, 42), rats (24, 26, 29), cats (21, 35, 42), dogs (19), rabbits (40, 41), goats (13), swine (52), bears (36), chimpanzees (49, 51), monkeys (66, 67), and even giraffes(22, 26). Other studies have involved authropomorphic dummies (25), and human cadaver materials (14, 18, 23, 30, 31), as well as theoretical mathematical analog simulations (38, 62, 65). While providing valuable estimates, such techniques may not provide data directly applicable to the human in the upper non-reversible trauma region (that is, that range between non-reversible injury and death). Conclusions, and thus prediction, are based upon variables which, although similar in some respects, are not identical. Figure I illustrates these different methods of studying impact. Note that voluntary human exposure may exceed the limits of reversible damage.

Materials and Method

Intensive case histories have been obtained on individuals who have survived accidental, suicidal, or homicidal free-falls. A free-fall is defined as an unimpeded drop of a body from a known point to a known impaction point. Although reports of unusual fall experiences are scattered throughout the medical literature, De Haven (11) in 1942 first analyzed trauma with respect to acceleration force in 8 cases of falls in the transverse plane (a ninth case was reported in 1948(12)).

To date over 12,000 cases of survived free-falls occurring during the past two years have been collected and filed. Reports of individual falls occurring throughout the United States arrive at the rate of approximately 30 per day, and include about 96% of all reported free-falls in this country. In addition to that on survived free-falls; information on approximately 5,000 fatal falls has been collected, including documentation with autopsy reports in some cases.

Availability of such a mass of material allows, as well as obviously requires, critical selection of cases for further investigation. Currently 137 cases have been subjected to intensive study. In each case selected investigation is personally conducted at the site of the fall and an effort is made to collect and obtain all information relative to the incident. To provide a reliable basis for bio-physical calculation of velocity and impact forces, the exact distance of the fall, position of the body at impact, material impacted and resulting deformation are obtained. Complete medical histories including roentgenograms, if taken, are obtained on each subject, and the injuries correlated with analysis of direction, magnitude, and distribution of force at impact. In addition, any other variable which could have a direct or indirect influence upon the particular case is noted. For example: had the subject been drinking prior to the fall? What sort of shoes was he wearing? It must be emphasized that it is imperative in a study of this nature that each factor be determined by personal investigation, because witnesses' memories are often inaccurate, the subject may know the least about what happened, and news accounts may overestimate the distances involved. Conclusions obviously can be no better than the basic data.

The cases generally selected for intensive investigation are those in which the distance of fall is great and the impacted object is one relatively non-giving, such as concrete. Particular interest has been focused on cases of vertical impacts of the buttocks or feet in ($+G_z$) headward accelerations. Abrupt deceleration commonly refers to impact of less than .02 secs duration, but, as is indicated by some of the cases in this study, may approach infinity.

It should also be pointed out that there is a mechanical difference between physical impaction, as in a fall, and a restrained impact involving a deceleration, which may result in somewhat different patterns of traumatic responses.

It is difficult to present these data without a brief comment upon the circumstances surrounding their causation. Two of the most common types of falls appear to be that of children falling from windows or porches, and of workment falling from scaffolds. Others run a wide gamut: a 91 year old male fell from a drawbridge while it was being raised, a

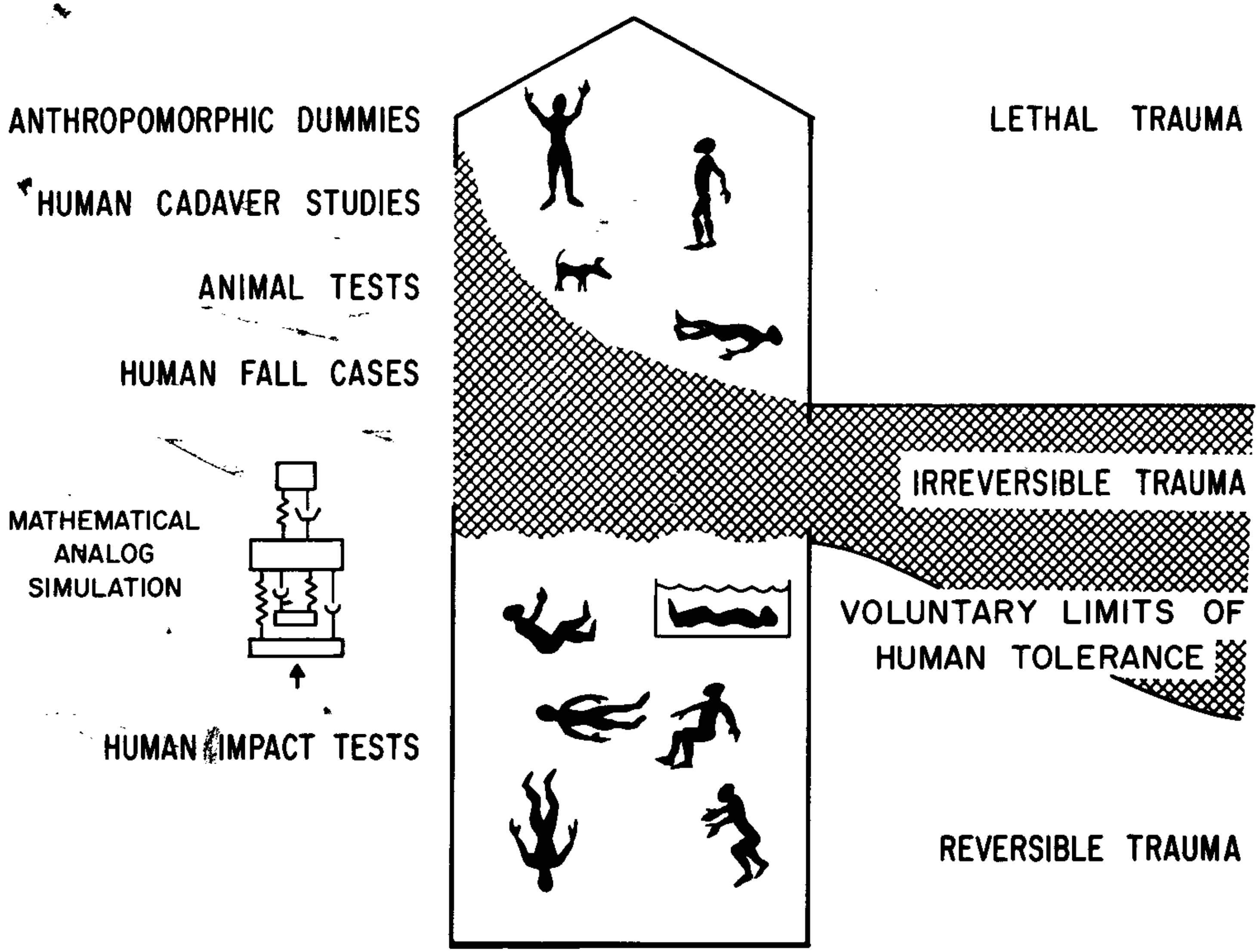

FIGURE 1. Methods of Determining Human Impact Tolerance.

75 year old male fell into a bombshelter he was constructing, a 69 year old female fell from a tree while chasing her pet parakeet, a locomotive engineer fell out of his cab, an eloper fell off the ladder (and had to postpone the wedding). Several individuals have dived into empty swimming pools, or fallen off roller-coasters, and others have been injured in attempting to escape over a prison wall. Construction on missile silos, off-shore drilling rigs, skyscrapers, elevator shafts, smokestacks, and water towers all produce survived (and fatal) falls of considerable distances, but usually do not provide usable data because the individual rolls or impacts at several points. Similarly, falls into wells or into mine shafts usually are not true free-falls because of friction with the sides due to slope or diameter. Another type of fall which is frequently not strictly a free-fall but often provides useful material is the sky-diver parachute failure. These are appearing with greater frequency as more individuals take up this sport. In 18 such cases reported in the last six months, three individuals have survived partial free-falls, two impacting at 50-70 mph. Accurate calculations on drag of partially opened chutes are usually precluded in such cases, but in one case photographs were obtained during descent and at impact, showing the exact profile. People have fallen from aircraft in flight, and of 52 such cases in the past year for which we have data, one individual survived for 12 hours an impact resulting from a fall of nearly 7 miles. Most falls appear to be accidental (and preventable): however some involve homicide or suicide attempts. Several investigations involved apparent infanticides, and there is always the questionable case which is classified officially as "accidental"—but could have been either suicide or homicide. Some 87 persons, for example, have "accidentally" fallen from the Golden Gate Bridge.

A free-fall occurring "in nature" may present factors as neatly categorized and analyzed as if accomplished in the laboratory. Usually, however, there are so many factors which may be involved in any one individual case that an analysis of this type involving a large number of cases becomes unwieldy in traditional treatment. Due to these many environmental factors which have been found to have varying influence upon the survivability of any particular fall, the biophysical and medical data are presented in terms of these intra-dependent variables found to date with related discussion included in each section. The variables are summarized in Figure 2.

I. *Orientation of the Body (Direction of Force)*

The position of the body in relation to force directly influences the nature and extent of injuries, since structurally the human body can resist greater forces prior to failure in some directions. In this study the majority of the impacts investigated were in the ($+G_z$) feet-to-head orientation, but five other positions were also commonly encountered. In addition, a small number were discarded either because of insufficient information concerning impact position or because they impacted in some other variation. Figure 3 summarizes, by sex, body position at impact in 128 cases studied.

The most common impact orientation in free-fall appears to be in the feet-first position. The sample is thus heavily skewed in this direction with 78 out of 128 falls, in which the direction of force was known, in this positive longitudinal acceleration axis.

The second most common fall position studied was head-first ($-G_z$) impacts. In each case care was taken to ascertain that the head was in fact the initial contact point, and that it took the brunt of the impact force prior to secondary shoulder impact. Although it might seem unlikely that an individual would fall head-first very often, even in suicide dives, it does occur, particularly in cases of electrical shock. Several of the best documented cases are those of workmen on steel girders being shocked, and subsequently falling head-first. In one such instance (Case #2017) the individual landed on the apex of his skull, only 8 inches out from the center of the beam after a fall of 13′ 4″ onto concrete. Surprisingly, he suffered only minor concussion and left the hospital after 24 hours observation. In such cases the fall may actually save the individual's life by re-initiating respiration.

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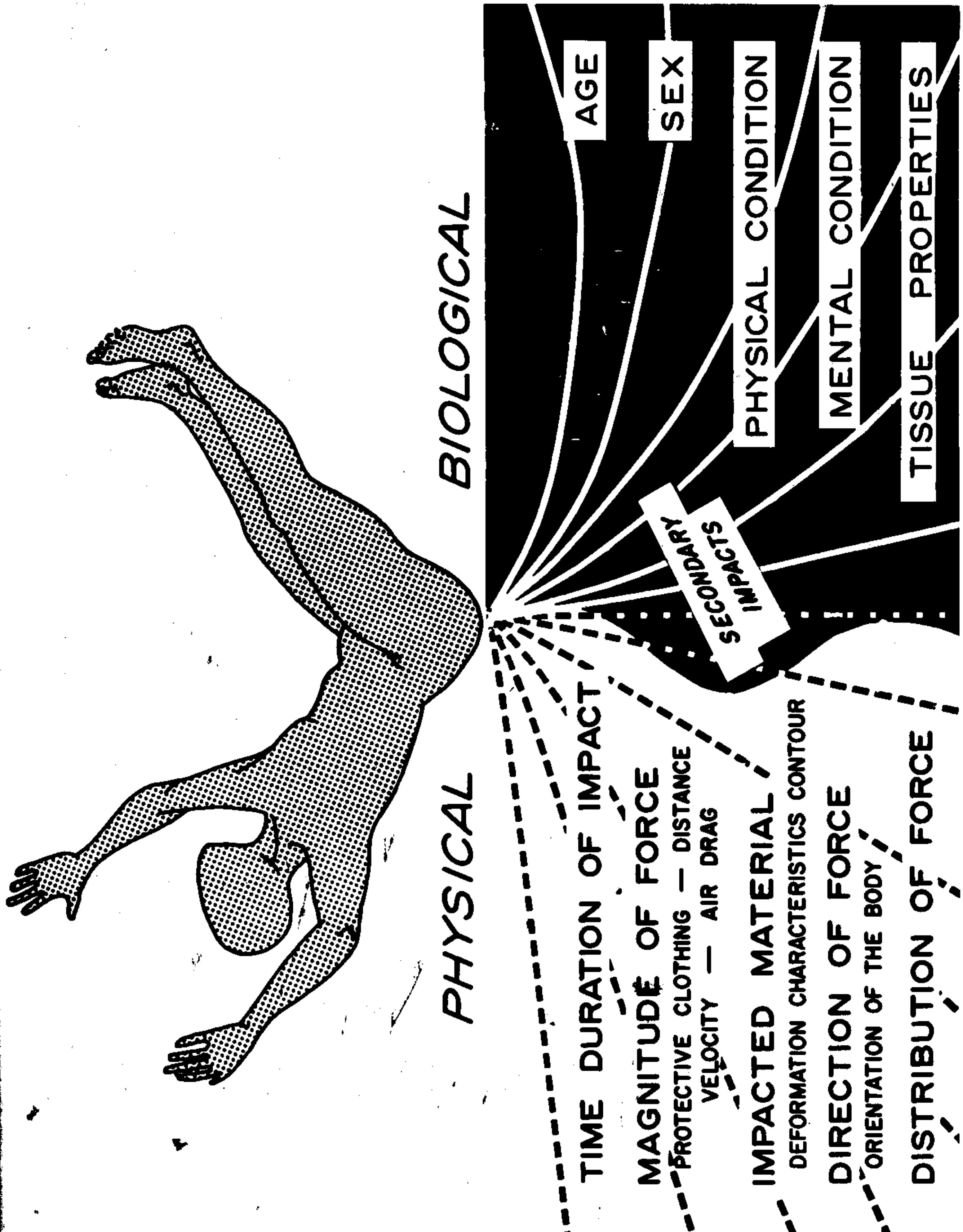

FIGURE 2. Biophysical Factors Influencing Trauma in Free Falls.

BODY ORIENTATION

IMPACT POINT		P.C.S.**	NO. OF CASES ♂ MALE	♀ FEMALE	TOTAL
FEET		$+G_z$	57	21	78
HEAD		$-G_z$	19	2	21
BUTTOCKS		$+G_z$	6	4	10
PRONE (A-P)		$-G_x$	3	0	3
SUPINE (P-A)		$+G_x$	3	0	3
HANDS & KNEES Transverse (A-P)		$-G_x$	3	2	5
SIDE Rt. & left Lateral		$\pm G_y$	8	0	8
Direction of Force	↑		99	29	128*

* (9 ADDITIONAL CASES LANDED IN SOME OTHER COMBINATION. 11 CASES UNKNOWN.)

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FIGURE 3. Body Position at Initial Impact.

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Falls in the buttocks-first position ($+G_z$) occur less frequently than other types of reported position, but 10 cases are listed here because an effort was made to follow-up on impacts in this position due to its' particular pertinence to crash forces in the vertical plane. This type of fall is also difficult to assess physically because, unlike the restrained laboratory subject, the individual is free to fall at any angle. Only under rare fortuitous circumstances can this angle be positively known, thus most can only be estimated to be between 90-135 degrees body position. To add to the complexity of this problem, the direction of force is occasionally changed by a "skidding" seated impact. For example, in two recent falls circus acrobats slipped while on the upswing on the bar and landed initially in a seated position, but with an additional forward momentum, causing the resultant angle of force to change about 90° in a very short time duration. Incidentally, unlike acrobats, high wire performers generally "fall dumb," that is, they have little or no experience in falling, even in practice, and simply do not even learn how to land properly in a fall. This may have contributed to two circus deaths in the last year.

Falls in the ($+G_y$) transverse sideward direction occurred in 8 cases selected, in the prone ($-G_x$) position in 3 cases, and in the supine ($+G_x$) orientation in 3 cases. Again this is not representative of actual frequency but rather selection.

One body orientation which must be classified separately is that of impact in a crouched position on the hands and knees. Usually this is along the $-G_x$ axis, and five such cases are included. To the author's knowledge deceleration tests on humans in this position have not been accomplished since it would appear to be an impractical working position. However, since trauma appears to follow a distinctive pattern, the position is included here.

The extent and severity of impact trauma are dependent upon many factors, but in general the patterns of injuries closely correlate with the direction of force and body orientation. Thus, in the $+G_z$ feet-first impacts, most severe structural trauma is related to the feet, ankles, and lower leg, while in the seated impacts pelvic and vertebral trauma are prevalent, and in the head impacts head, shoulder girdle, and thoracic injuries are most noticed, as would be expected. Table I shows the anatomical distributions and frequencies of trauma in feet-first ($+G_z$) impacts. It is interesting to note that more of the 152 fractures involved occurred on the left side of the body in the 78 individuals in this group.

These injuries are fairly typical of the fall trauma treated in general orthopedic practice, that is, a high proportion of fractures of the calcaneus, distal fibula and distal tibia, midshaft of the femur and lumbar vertebrae, particularly L-4-T-12 area. Ciccone, (8) found that in experienced parachutists, fractures of the posterior tibial margin and multiple metatarsal fractures were prevalent. (see also 37, 45) Most of the fractures of the upper extremities, such as distal radius, humerus, and injuries to the skull, are not a result of initial impact but probably occur during secondary impacts. The most prevalent damage to internal structures is to the lungs and kidneys, with hematoma of the renal pelvis most frequent.

Table II provides an overall view of the relationship between fracture patterns in free-fall and the direction of force. The majority of fractured skulls occurred in the head-first ($-G_z$) impacts as would be expected, but also occurred to a minor extent in feet-first and buttocks-first ($+G_z$), impacts, probably as a result of secondary impact. Foot and ankle fractures occurred in the buttocks, hands and feet, and feet-first ($+G_z$) impacts. No fractures were reported in the supine or prone position ($+G_x$) but only six individuals impacted in these positions. Buttocks first (seated) impacts ($+G_z$) are largely characterized by fractures of the pelvis (31%) and vertebrae (23%), but fractures of the legs (tibia, fibula, femur) occurred only in side ($+G_y$) and feet-first ($+G_z$) impacts.

II. Distribution of Force

As with each of the factors listed, distribution of force at impact cannot be adequately considered independent of other factors. Findings indicate that the distribution of force through the body is intimately connected with

BODY REGION			NUMBER OF FRACTURES Left		Right
A. FRACTURES					
1.	Skull:	Temporal	1		1
		Frontal	1		
		Occipital	2		
		Maxilla	1		
		Mandible	2		
		Nasal	2		
2.	Upper Extremities:	Humerus	2		3
		Ulna	2		1
		Radius	4		
		Carpals	1		2
		Phalanges	1		
3.	Trunk:	Scapula	3		1
		Ribs - 5th	1		
		6th	1		
		7th	2		
		8th	1		
		11th	1		
		Cervical vertebrae		1	
		Thoracic vertebrae			
		T-3		1	
		T-7		1	
		T-10		1	
		T-11		1	
		T-12		4	
		Lumbar vertebrae			
		L-1		9	
		L-2		5	
		L-3		5	
		L-4		5	
		L-5		3	
	(Pelvis)	Sacral vertebrae	2		1
		Pubic ramus	2		2
		Ischium	2		1
		Ilium	1		1
4.	Lower Extremities:				
	(Leg)	Tibia	4		4
		Fibula	6		2
		Patella	2		2
		Femur	5		5
	(Ankle)	Cuneiform	1		
		Cuboid	3		
		Navicular bone	3		
		Talus	3		2
		Calcaneous	12		6
	(Foot)	Metatarsals (4)	2		1
		Phalanges (2,3,5)	4		
B. SOFT TISSUE INJURIES					
	Cerebral contusion			1	
	Hematoma, right occipital area			1	
	Hematoma, right temporal area			1	
	Lungs: pneumothorax (1 bilateral)		2		2
	hematoma		2		
	Kidney, hematoma		5		
	Bladder (displaced by hematoma)		2		
	Testes, contusion		1		

TABLE I Relation of Body Orientation (Direction of Force) to Trauma [illegible] Feet-first ($+G_z$) Impacts. Anatomical Distribution and Frequency in 78 Ca

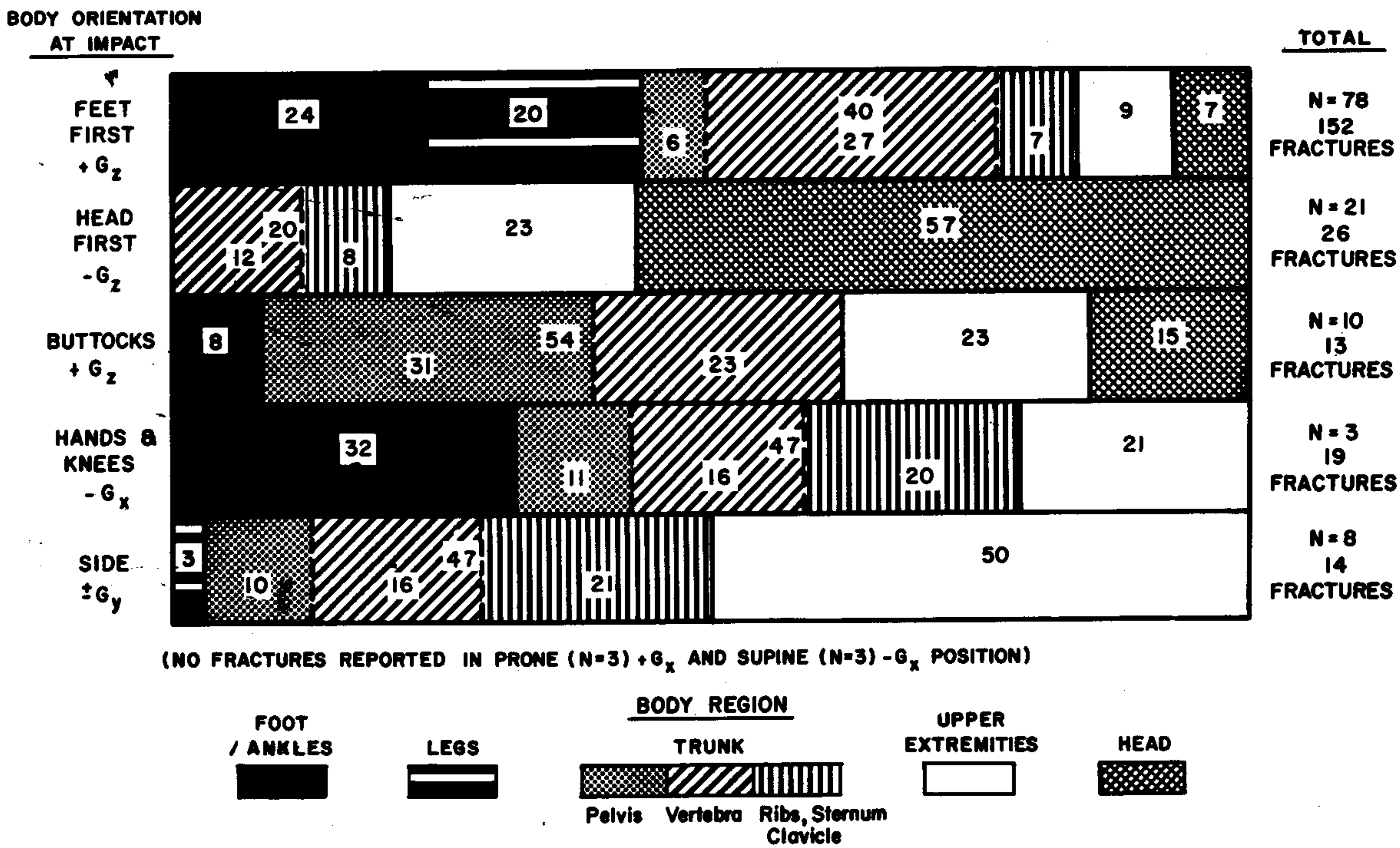

TABLE II Relationship of Fracture Patterns in Free-Fall with Direction of Force.

magnitude, orientation of the body (direction of force), and time duration, among other factors. It is generally considered that the greater the area over which the load is applied, the smaller the load per unit area. This principle has been applied to restraint systems which aim to distribute the load over the skeletal framework of the body rather than subjecting soft structure, such as the abdomen, to extensive pressures. While the results of this investigation are not conclusive as to variations in the distribution of force in free-falls, an interesting paradox is observed. Thus in 12 cases of survived falls of over 100 feet distance, 10 initial impacts were in the feet-first position. Both feet provide an approximate surface area generally not exceeding 67 sq. inches in normal weight-bearing for males, and 45 sq. inches for females. While the assumption that concentration of force over a small surface area, such as the feet, may be theoretically not as desirable as distribution of force over a large area (as in the prone or supine position), the evidence from the 78 feet-first impacts indicates that this may not be as critical a consideration as other factors. While one can object that selection of cases has resulted in a skewed distribution of free-fall survivals in the feet-first ($+G_z$) position, these cases do represent the extreme survival position most readily occurring. Force is apparently greatly attenuated in $+G_z$ impacts by bending and flexion of the leg muscles, as well as tissue and structural attenuation. On the other hand, in cases of free-fall where the individual has been impaled on a fence, or straddled a narrow steel girder in a prone position, the concentration of force at structurally weaker points has contributed to much more severe injuries.

Distribution of force is directly related to the transmission and dissipation of energy throughout body tissues. Most deceleration studies have been concerned with this distribution in body orientations of the seated forward-facing or backward-facing position. Feet-first impacts have previously been independently studied by Swearingen (60) and by Hirsch (25), regarding injuries to lower extremities of naval personnel due to deckblast of underwater explosions, and by Swearingen *et al.* (61) in voluntary human drop tests. In this latter study it was found that subjective tolerance levels for individuals impacted in rigid seats and in the standing position with knees locked were identical (10 g at 600+ g/sec at shoulder level), with input loads at 65 g at 10,000 g/sec for the standing position and 95 g at 19,000 g/sec for the sitting position. The difference in transmission rate was considered due to the difference in the rigidity of the skeletal system in the standing position as compared to the seated compressibility of the gluteal musculature. In addition, Swearingen found that there was an attenuation of only 6-10 times, but a very rapid transmission (400-1000 ft/sec), in feet-first impacts with the knees locked, while impact forces "were attenuated 36 times by bending the knees." Ciccone and Richman (8), in studying the mechanism and distribution of injuries in 3,000 fractures in parachute jumping, noted that landing stiff-legged, typical of the untrained individual, usually resulted in a fractured heel. Thus the degree of voluntary bending of the knee during impact appears to be quite important in degree of injury in feet-first impact. With this in mind an effort was made to learn from the free-fall subjects whether they were relaxed or tense (stiff-legged) during the fall. Some individuals reported that they were "petrified" or "scared as hell" during the fall, while others claimed to have been relaxed. Such subjective answers are of questionable reliability, but those who claimed to have relaxed and remembered impacting with bent knees did appear to suffer less severe injury.

III. Magnitude of Force

Force magnitude and time relationships are generally expressed in terms of the familiar g load and "rate of onset." In this study, magnitude is described in terms of the velocity of free-fall at impact, thereby providing a basis for comparing cases and for making further calculations as desired. Some of these falls involve such a short time duration, considerably less than in previous human experiments, and with such ultra-high impact velocity, that the calculated g forces often exceed 5000 in survived falls with rates of onset into the millions of g's per second. Not only are the g forces as much as 70 to 100 times the highest magnitude experimentally studied with human volunteers, but the time durations may approach zero. As impacts at this extreme are approached many puzzling questions arise. Based upon voluntary impact tests lethality would be expected to increase as magnitude increases, but the fall cases to date do not show a positive correlation with degree of trauma based upon magnitude alone. It is possible that human tissues may react differently to impact energy if subjected to a high enough force in an extremely short time period.

Velocity in free-fall ($V = \sqrt{2gS}$) is mainly dependent upon distance fallen, requiring about 482 feet at sea level to reach a terminal velocity of 120 mph, where S = distance and g = 32.1739 ft/sec^2 (980 cm) at sea level. The value for g varies with location, thus is 32.12 ft/sec^2 at Key West, Florida, and 32.23 ft/sec^2 at Fort Egbert, Alaska. Distance in all free-falls was measured, utilizing either a standard steel tape measure (100′), or a specially designed 250′ weighted wire tape on a U-control friction reel, and, in one case occurring on the Golden Gate Bridge, by an engineer's transit (46). The fall distances and velocities for 137 cases are plotted in Tables III and IV.

As previously noted, a case is not selected for intensive study on the basis of distance of fall alone. Thus, individuals have survived falls of considerably greater distances than these, but if other pertinent information is found to be unreliable, the case is not considered further.

In the past two years at least 90 persons have survived falls of 100-900 feet, and 9 have survived falls of over 1000 feet. However these have generally precluded accurate study because of complicating or doubtful data.

Velocity of free-fall has been shown, first by Galileo and subsequently by more exacting experiments including those by Albert Einstein, to be independent of mass. However there is considerable evidence to indicate that air drag does affect the velocity of the falling human body. Schmitt, (43) in conducting wind tunnel experiments on subjects at several Yaw angles and in five body positions obtained drag coefficiens for predicting drag forces on men of average stature under a variety of conditions. More recently Cotner (10) has employed a closed-form solution for velocity at impact for fall cases where body position and clothing condition were observed to be constant. Other work is in progress by Earley and the author to determine the air resistance effects on velocity in free-fall. Velocity on the cases presented in this paper has been corrected for air drag as calculated in Figure 4 by Earley. A mean body build of 4.7 C_DS (drag coefficient × total body surface area) was utilized, at which terminal velocity is 120 mph.

In each case a careful description of clothing worn at the time of the fall has been noted, along with such body data as height, weight, and body build. In most cases, clothing would probably cause little drag, but in some cases an overcoat, a light poplin jacket, or large skirts could have a greater effect. This is an area which will require further investigation.

Classic studies of falling bodies have been performed on solid homogeneous materials, and the calculation of G forces assumes a constant force during acceleration. Impact acceleration of a non-homogeneous body, however, does not always act in this theoretical manner. If the assumption is made that the reaction varies linearly with the deformation of the yielding reaction surface, the deceleration during impact would also vary linearly and the peak acceleration would be twice the value calculated on the assumption of standard deceleration. At impacts of very great magnitude and ultra-short time durations this point, although generally overlooked, becomes critical in calculation of impact forces. This also brings up the nasty question of just what is being measured. In the case of a falling body it is presumed to be a calculation of the energy imparted at the initial point of contact to the outermost body structure (being greatly dissipated as it is transmitted throughout the body tissues). Use of velocity at impact, in ft/sec, may provide a more meaningful basis for comparison of the magnitude of force in free-fall impact.

IV. *Material Impacted*

The object impacted in free-falls is of great importance as an injury or even survival determinant. The relative elasticity or solidity of

VELOCITY			
STANDARD	CALCULATED		DISTANCE
ft/sec $V=\sqrt{2gS}$	ft/sec	mph	
44.42	44	30.0	30' 8"
43.94	43	29.3	30'
43.69	43	29.3	29' 8"
42.45	41	27.9	28'
41.68	41	27.9	27'
40.90	40	27.3	26'
40.31	40	27.3	25' 3"
40.11	40	27.3	25'
39.71	40	27.3	24' 6"
39.30	39	26.6	24'
38.89	39	26.6	23' 6"
38.47	38	25.9	23'
36.98	36	24.5	21' 3"
36.76	36	24.5	21'
36.39	36	24.5	20' 7"
35.87	35	23.9	20'
35.42	35	23.9	19' 6"
34.51	35	23.9	18' 6"
34.04	33	22.5	18'
33.56	33	22.5	17' 6"
33.07	32	21.8	17'
32.66	32	21.8	16' 7"
32.09	31	21.1	16'
31.41	31	21.1	15' 4"
31.07	30	20.4	15'
30.28	29	19.7	14' 3"
29.74	29	19.7	13' 9"
29.47	29	19.7	13' 6"
29.28	29	19.7	13' 4"
28.55	28	19.1	12' 8"
28.08	28	19.1	12' 3"
27.79	27	18.4	12'
26.61	26	17.7	11'
25.78	25	17.0	10' 4"
25.40	23	15.7	10'
24.72	23	15.7	9' 6"
24.07	22	15.0	9'
22.68	21	14.3	8'
21.23	20	13.6	7'
19.24	18	12.3	5' 10"
17.01	13	8.9	4' 6½"

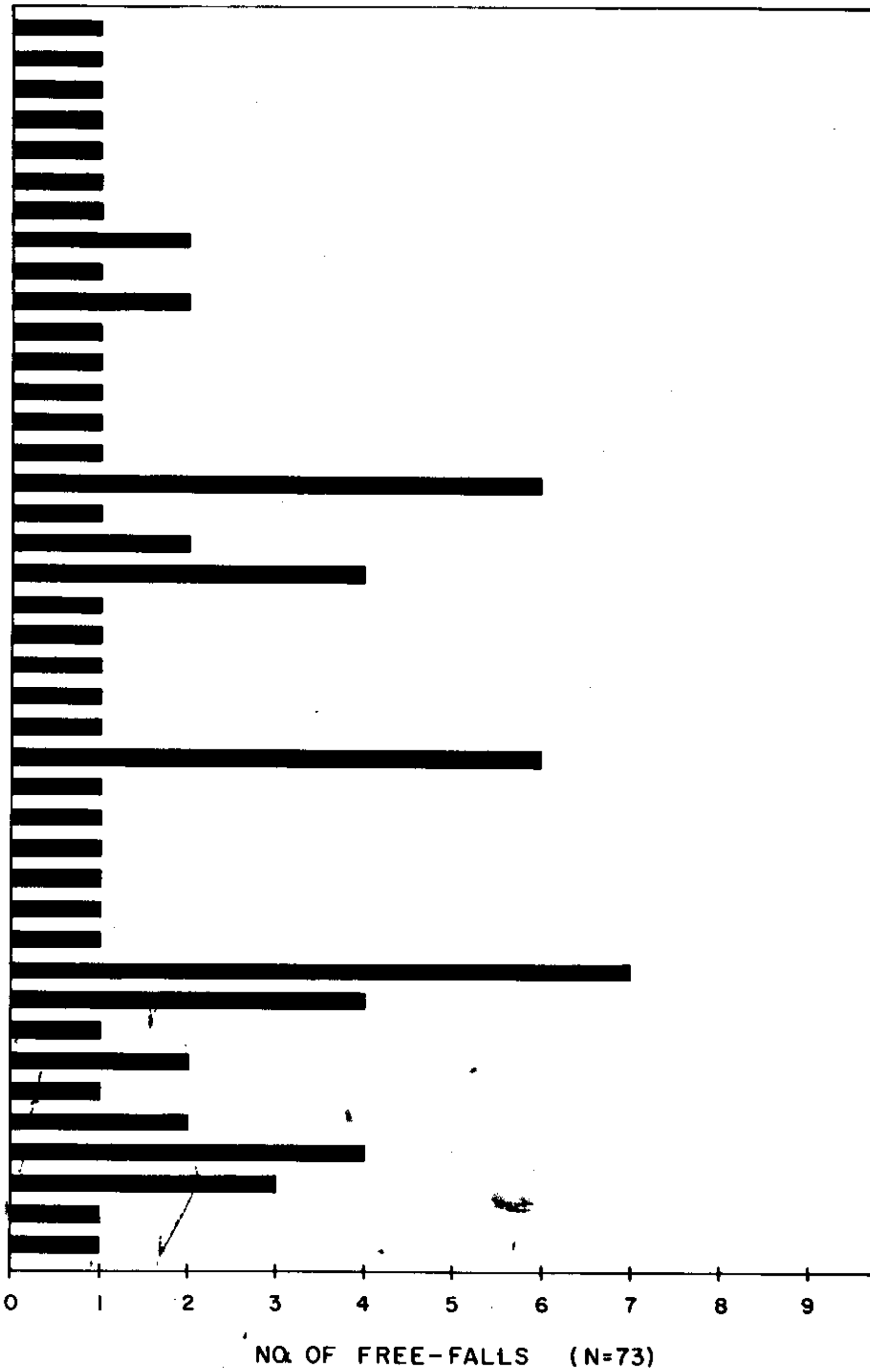

TABLE III Distance Fallen and Velocity for Free-Falls Survived Up to 30 Feet.

VELOCITY			
NDARD	CALCULATED		
/sec √2gS	ft/sec	mph	DISTANCE
33.03	116	79.1	275'
25.82	111	75.7	246'
16.98	106	72.3	220'
16.44	105	71.6	218'
07.03	97	66.1	178'
04.59	96	65.5	170'
93.21	86	58.6	135'
91.47	85	57.9	130'
88.43	82	55.9	121'6"
85.01	80	54.5	112'4"
82.98	78	53.2	107'
80.22	76	51.8	100'
76.95	73	49.8	92'
76.10	72	49.1	90'
75.68	71	48.4	89'
75.07	70	47.7	87'7"
73.96	70	47.7	85'
73.52	69	47.0	84'
68.07	65	44.3	72'
67.59	65	44.3	71'
67.12	64	43.6	70'
65.66	62	42.2	67'
64.67	61	41.6	65'
63.16	61	41.6	62'
62.14	60	40.9	60'
60.92	59	40.2	57'8"
59.49	57	38.8	55'
56.72	55	37.5	50'
55.58	54	36.8	48'
53.46	52	35.4	44'5"
51.99	51	34.7	42'
50.73	50	34.1	40'
50.10	49	33.4	39'
49.50	49	33.4	38'1"
48.80	48	32.7	37'
48.63	48	32.7	36'9"
47.46	47	32.0	35'
46.43	46	31.4	33'6"
46.08	46	31.4	33'
44.67	44	30.0	31'

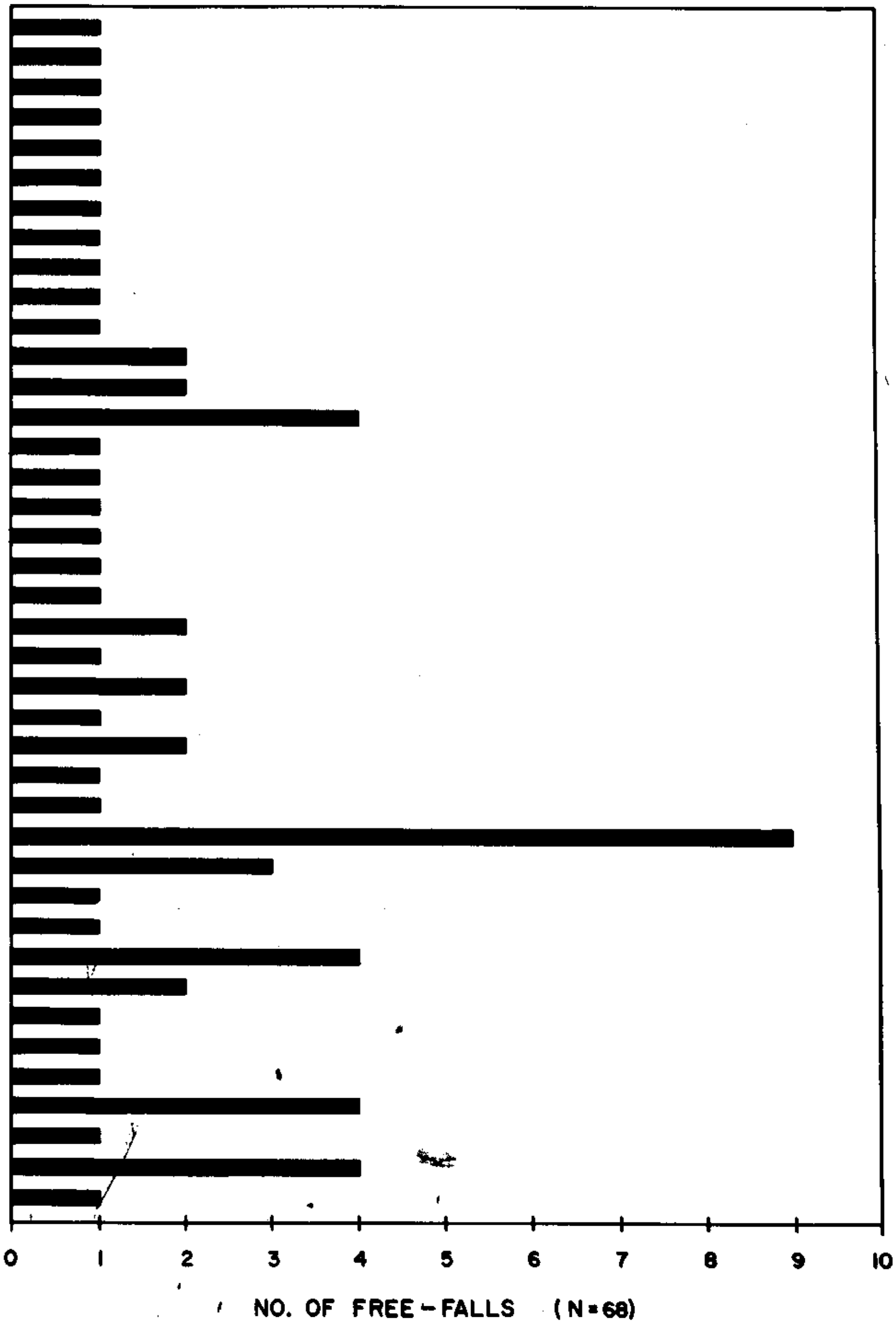

TABLE IV Distance Fallen and Velocity for Free-Falls Survived 31 to 275 Feet.

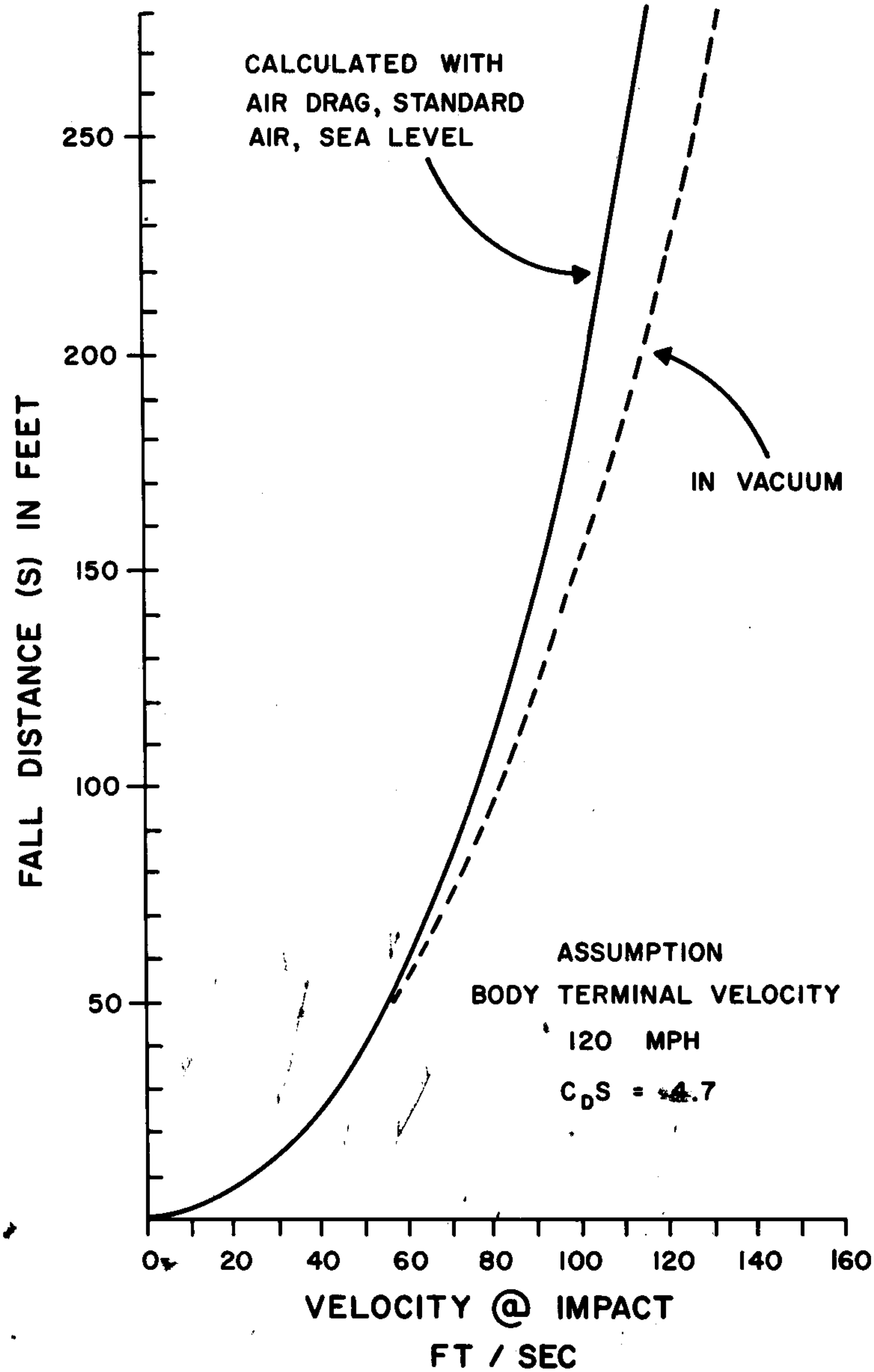

FIGURE 4. Calculated Velocity in Free-Fall.

structure directly affects the deformation distance and thus the time duration of impact. It also may affect survival by its contour characteristics. Thus soft, muddy ground is obviously preferable to jagged rocks upon impact.

Survived free-falls have involved the following impact materials: concrete (45 cases), asphalt roof or macadam pavement (9 cases), soil, ranging from rocky to sandy (45 cases), granite (1 case), flagstone (1 case), steel (11 cases), water (9 cases), snow (2 cases), wood (5 cases), and a pile of manure (1 case). Cases of impacting on concrete, steel, and rock (flat) surfaces have been especially selected in this investigation because of the non-yielding characteristics of the impact material. Since accurate calculations of time duration at impact ($T = 2\ S/V^{\circ} - V_1$) are dependent upon the variable of distance of deformation (S) of the impacted object, utilizing non-yielding objects greatly increases the reliability of the calculations.

To determine the maximum deflection of concrete upon impact, the following calculations were made by K. K. Kienow of Concrete Conduit Corporation.

In the first case a 4″ thick slab of concrete, 4′ wide and 10′ long and having a uniform soil pressure underneath (elasticity of the soil results in maximum deformation of the concrete), was loaded at the center to determine the maximum deflection ($\triangle$) which could be attained prior to concrete failure by cracking.

$$I = \frac{bh^3}{12} = \frac{48(4)3}{12} = 256\ in^4$$

$$S = \frac{I}{2} = 128\ in^3$$

deflection diagram

moment diagram

$$WL^2 = M$$

$$\text{Max moment} = \frac{WL}{2} \times \frac{L}{4} = \frac{WL^2}{8} = M$$

By Moment Area:

$$E^1\triangle = \frac{LM}{2} = \frac{1}{3} \times \frac{3}{4} \times \frac{L}{2} = \frac{3ML^2}{48} = \frac{ML^2}{16}$$

$$\triangle = \frac{ML^2}{16EI} \qquad L = 10' = 120''$$

M max (w/o cracking) =

$$FS = 400 \times 128 = 51{,}200\ in\#$$

$$(F = \text{cracking} = 400\ psi)$$

$$\triangle = \frac{51{,}200 \times \overline{120}^2}{16 \times 3 \times 10^6 \times 256}$$

$$= 15.6 \times 10^{-3} = .0156\ \text{Maximum}\ \triangle$$

In this case the cracking moment, that is, the maximum the concrete could deflect prior to cracking, was calculated to be .0156 inches. This forms a basis for the upper limit of concrete deflection, which is independent of force.

In a second case, a 4″ thick slab of concrete, also 4′ wide and 10′ long, was loaded at the center (assuming an unyielding foundation), although the concrete itself deflected. In this case a 200 pound man was assumed to impact feet first (1 square ft area) at a velocity of 65 ft/sec, with velocity after impact zero (no bounce).

$$\text{mass of body} = \frac{200\ \text{lbs.}}{32.2} = 6.21\ \text{slugs}$$

$$1\,F\triangle = 1\,mv^2$$

$$\triangle = \frac{PL}{AE}$$

$$A = 1\ \text{sq ft.}$$

$$L = t = 1/3\ \text{ft.}$$

$$E\,FT^2 = Ein^2 \times 144$$

$$P = F$$

$$\triangle ft = \frac{F \times 1/3}{1 \times 144E} = \frac{F}{432Ein^2}$$

$$\text{or}\ F = 432E\triangle$$

subs in 1

$$432\text{Ein}^2 \, \Delta^2 = \frac{1}{2} mv^2$$

$$432(3 \times 10^6) \, \Delta^2 = \frac{1}{2} (6.21) \, 65^2$$

$$1300 \times 10^6 \, \Delta^2 = 13{,}000$$

$$\Delta^2 = \frac{13{,}000}{1300 \times 10^6} = 10.1 \times 10^{-6} \text{ ft}$$

$$\Delta^2 = 3.22 \times 10^{-3} \text{ ft}$$

$$\Delta \text{in} = \frac{3.22 \times 10^{-3}}{12} = 268 \times 10^{-3} \text{ in}$$

$$= .000268$$

In this minimal case the deformation was determined to be .000268″. Any bounce, of course, would decrease this figure, and most free-fall impacts do appear to involve bounces. Obviously, in either case of concrete impaction, practically all of the energy of the falling body would be dissipated within the body tissues. In both cases no bounce was assumed, but any bounce would decrease these figures. On the basis of these calculations it seems evident that the cracking moment (maximum deflection) of concrete will range from only 1/100th to 2/10,000ths of an inch. However, since no cracks were found in any of the concrete impacts these limits probably were not reached.

Water provides an entirely different problem, since its relative deformation (depth individual goes to, and elastic properties) may vary considerably with the surface area of the body, orientation of the body, and condition of the surface of the water (e.g. trough, wave, or smooth) as well as velocity of the current. High divers attempt to cleave the surface with their hands and consistently make dives of over 100 feet into small pools (of still water) without apparent injury. All survived water impacts to date in our series were feet-first, possibly indicating that exposure of the least surface area is important to survival. Further tests on water impact are planned.

Steel provides an even stiffer surface, but deformation may actually be measured by a permanent "bow" in the structure. Soils vary in hardness and to date no relative soil tests have been made, although a relative index (r value) will be made on a basis of soil samples in future cases. Wood often deforms considerably prior to breaking in impact, but presents problems of different thickness, kinds of woods, and support, among other factors.

To study the relationship between surface impacted and trauma the cases were compared, taking into account the bias of selection and relatively greater proportion of soil and concrete impacts. A preliminary comparison (not presented due to length), contrary to expectations, does not show a straight-line relationship based upon relative hardness of material. Instead injuries (and fatalities) are distributed in severity throughout the range of material impacted, with survival with relatively minor clinical evidence of trauma or, in some cases no discernible injury, occurring about as frequently on concrete impaction as upon soil impaction. This is probably due to the complexity of factors, which must be considered in each case.

V. *Time Duration*

One of the most critical factors in deceleration, as in acceleration, is that of the duration of time that the force is applied. In impact this generally refers to the time required to reach the peak force at initial impact. While linear and radial acceleration experiments may last for a period of seconds or even minutes, and voluntary human deceleration tests for .004 to .42 seconds (53), the very abrupt impacts associated with human free-falls often range considerably lower and actually approach zero when impacts against non-yielding rock or concrete surfaces are encountered.

The importance of the duration of time the force is applied has been emphasized by previous investigators, and findings by Stapp indicate that when this duration "is less than 0.2 seconds, the tissues react with damage to structural integrity, behaving like inert materials under conditions of mechanical stress analysis, where structural damage and failure are independent of gradients of fluid displacement." (53, p.173). Thus no fluid shift apparently occurs if the impact duration is short enough.

But even though force varies linearly with distance we do not know how force varies with time in abrupt duration impacts. How force varies with time, or how deformation varies with time, is still empirically unknown. Maximum deformation of the impacted surface provides the maximum force, but not necessarily time involved. In long duration accelerations of low magnitudes, such as with the centrifuge, forces can be controlled with respect to time, and this is also true of some braking systems on high speed deceleration tracks. In human free-falls, on the other hand, it is impossible to instrument the experiment beforehand. At the present time insufficient data are available on controlled tests at very high impact velocities to provide a valid basis for much needed refinements in calculations and assumptions as to the exact nature of the time-force history of the event. It is very difficult, for example, to find materials that yield uniformly to constant force.

Impact by definition is of extremely short time duration, and yet a major problem is that we are as yet unable to adequately identify the impact dynamics as functions of time. For the present, construction or employment of a time index will allow some meaningful measuring system to the impact events or study. In recognition of this difficulty the classical but imperfect description of impact time is derived by assuming the velocity is a linear function with respect to stopping distance. Time is thus expressed as a simple expression,

$$t = \frac{S}{\frac{V_1 - V_0}{2}} = \frac{2S}{V},$$

or time equals distance divided by average speed.

It is generally considered that there may be a positive relationship between magnitude, time duration, and degree of trauma. This has resulted in various cushioning materials in ejection seats, for example, to distribute force through a greater time period. Many fall cases bear out this expectation, i.e., that the greater the time duration the less the injury received. The following cases, for illustration, involve individuals each of whom fell a measured distance of 50 feet (5 stories), impacting on their feet ($+G_z$). All impacts were at 56 ft/sec or 38 mph (corrected for sea level, standard air):

(1) An 18 year old Caucasoid male jumped (or fell) from the roof of a 5-story apartment building. The soil in which he impacted had been so saturated by rain that he sank into the ground 18 inches, distributing the force of impact over .054 seconds. No apparent injury.

(2) A 15 year old Caucasoid male fell from a ranch silo after being distracted by wasps. He landed in a pile of hard-dry cow manure, which cushioned his impact an estimated 3 inches. He bounced, and fell on his right side, fracturing his right wrist, an injury due to secondary impact. Time duration: .0043 seconds.

(3) A 38 year old Caucasoid female fell from a cliff, landing on her feet in loose gravel, and injuring her back in secondary impact. Time duration: .006 seconds.

The resilient qualities of these impacted materials, which deformed in response to the force applied over a relatively long time period, were evidently quite effective in decelerating the body with minimal, or no injury, in these cases.

However, the most puzzling data resulting from this investigation is that some individuals survive free-falls terminating on non-yielding rigid structures at exceedingly large magnitudes of force with minor injury or, occasionally, with no apparent clinical trauma. In each of these cases the time duration is ultra-short.

For example:

(1) a 40 year old Caucasoid male committed infanticide and then attempted suicide, jumping a distance of 44′ 5″ from the roof of a tenement. He landed, barefoot, on a granite block at the sub-basement entrance-way. His only injuries were a minimal fracture of the right pubic ramus and of a cervical vertebrae. He remained conscious after impacting and wandered off, despite impaction at 53.46 ft/sec

(36 mph), at *.0006 secs. time duration* (assuming granite block deflected 016 inches). Police at first refused to believe that he had jumped.

(2) A 36 year old Caucasoid female, attempting suicide, jumped 71 feet from a 6 story building roof, plunged through a skylight (without touching the framework) and impacted on a concrete floor. No clinical injuries were found except for cuts and abrasions. She impacted at 65 ft/sec (44 mph) at *.0004 seconds time duration* (assuming concrete deflected its maximum value of .016 inches).

According to past research indications, these individuals should have received fatal injuries, and yet each was only superficially injured. Time durations of .0004 to .0006 seconds are only 1/10th of the briefest time (.004 secs) reported in human voluntary deceleration experiments, and add to the possibility that, if an individual is very abruptly impacted, the tissue response may preclude serious injury.

There is the possibility that, for time durations below a certain range, possibly .0006 seconds, where body tissues do not always apparently respond as expected, survival may increase under certain conditions. One example is the use of Karate, originally developed during the Tang dynasty in China as a form of self-defense by peasants restricted from having other weapons. Long years of training by the expert, in which the individual strikes the inside of his thighs with the edge of his hand, forms extensive scar tissue pads on both the inside of the thigh and edge of hand. Although the abrupt, powerful Karate blow is normally aimed at a portion of the body, a Karate "black belt" expert can reportedly crack solid wood with a single blow. This impact between human tissue and a hard surface may have a direct bearing upon fall survivals in the very short time duration range, and ancillary Karate tests and measurements are planned.

VI. Physical Condition

The general physical condition of the individual at time of impact is probably quite important to the degree of injury received as well as recovery prognosis. In voluntary deceleration tests, subjects have invariably been males in good physical condition. Thus it may be assumed that these tolerances established at lower impact loads are close to the maximum levels of voluntary tolerances for males.

Data from this study, dealing with a much wider segment of the general population, appears to be in general support of this thesis. Some of the most remarkable falls have been survived by males who were athletes in excellent physical condition. Similarly, the majority of the female impacts of greatest velocities were survived by healthy young females. As many other studies have shown, the body is obviously better able to cope with force fields if it is in an optimum condition.

In a small number of instances previous fall training may help to prevent more serious injury. Thus certain athletes are well equipped to survive a fall by knowledge of how to fall, roll, and recover. This would particularly apply to wrestlers, tumblers, and judo (ju-jutsu) experts. In addition, circus acrobats, by developing muscular co-ordination and training, can fall long distances successfully without injury. (Most of the fatal and serious falls occurring in circuses are to high-wire performers or other specialists not trained in falling.) Parachutists, a class of highly-trained specialists in fall techniques, are taught to land on their toes, with feet together. They also keep their knees and hips slightly flexed, relaxing the muscles somewhat to absorb the shock at moment of impact. Such individuals are usually in excellent physical condition, which certainly contributes to survivability. Several ex-paratroopers are included in this study. However too few cases have been obtained to date for further comparison.

Experiments by Matthews and Whiteside on the neurological state of human subjects who are suddenly dropped in a chair, have resulted in some pertinent observations. They suggest that when a muscle becomes weightless "the tensions are suddenly reduced in upper attachments and increased in the lower; a group of muscle fibers which had been exerting sufficient contraction to maintain an isotonic state suddenly act unopposed, and therefore shorten" (34, p. 203). These movements within the muscle due to the abrupt change in acceleration in falling they interpret as being responsible for the absence of reflex. Due to the critically short impact durations often encountered in free-falls, the physical properties of human tissues may respond in acutely abnormal reactions. Time durations of .0006 seconds, or less, may actually preclude a normal tissue response. Impact may simply occur so suddenly that the body tissues do not have time to respond in sequence.

The non-homogeneity of body structures with resulting complex reactions to force applications have always hindered predicability of soft-tissue trauma. Very brief time durations of force may well result in tissue behavior similar to that of inert materials. Physical properties of tissues subjected to mechanical stresses involving compression, tensile and shearing strengths, elasticity, viscosity and frequency response must be considered, and have been under study by a number of investigators. The human body is of heterogeneous visco-elastic composition, and human variability cannot be over emphasized.

Taking these 137 free-fall cases as a whole, the clinical histories show a disproportionate incidence of internal trauma to what would be expected on a basis of extension of voluntary tests. In a few cases, there was the unique opportunity to compare the clinical diagnosis with the autopsy report of the pathologist. It is believed that follow-ups of fall cases in which the patient subsequently dies of his injuries and is autopsied may provide particularly useful comparative data now lacking, and it is hoped to pursue this course in the future. Internal trauma may provide difficult diagnostic problems coupled with the fact that, unless severe injury is involved, the tissues may recover without further assistance from the physician. It is suspected that supporting tissue structures such as the peritoneum, mesentery, or ligaments are often damaged in impact but are not diagnosed due to more painful complications masking such injuries. This is indicated by the fact that interviewed fall patients often complain of such things as "pain in the lower abdomen," "testicles hurt," etc., which often match the subjective symptoms found at the non-reversible injury threshold in voluntary subjects exposed to velocities up to 19.6 ft/sec by Swearingen (60). At 24 ft/sec (a 10 foot fall) to 33 f/sec (18 feet) complaints were very similar. One 69 year old male (Case #2006) falling 25'3" (40 ft/sec) and landing on his feet also noticed considerable testicular pain subsequent to the fall. In an autopsy of a 28 year old male who received fatal injuries (Case #2022) in a feet-first impact, numerous small areas of hemorrhage were found in the left testis. Thus it is felt that internal injuries may be more prevalent than the clinical histories of these fall victims would indicate.

VII. Mental Condition

The majority of free-falls occur accidentally. Falls officially listed as suicide or homicide compose only a minor part of the total although some cases are not so neatly classifiable. Thus there is a distinct difference in motivation: the individual in the accidental fall, or one who is thrown off a cliff by another person in a homicide attempt, does not consciously want this action to occur. On the other hand, the individual attempting suicide by jumping is initiating purposeful action.

A large proportion of free-falls from the greatest heights have involved suicide attempts. For example, in the 11 falls of over 100 feet distance studied to date, 7 (and probably 9) were deliberate suicidal leaps. In our society this is generally conceded to be abnormal behavior manifested by an abnormal psychotic condition.

In comparing the medical histories of this group of attempted suicides a striking common factor in many of these cases was the diagnosis of "paranoid schizophrenia." Since these individuals had all survived free-falls of unusual distances and under calculated impact forces exceeding 75 ft/sec, it would seem proper to explore further the hypothesis that psychotic patients may be able to withstand impact forces more successfully than "normal" individuals. It is interesting, in this respect, to note that the psychotic patient differs primarily in one important respect in regard to falling — he wants to jump. The act of jumping may thus be a release for him, and unlike most of us, this individual may enjoy the jump. As a result he may be physically relaxed at the time of impact, which appears to be, in itself an important criterion for survival of free-fall.

A second factor found in this study, and believed to be of importance, is the incidence of intoxication among free-fall survivors from high jumps. Along with psychotic patients, inebriated individuals also appear to have a disproportionate survival rate among free-falls of extreme distances. But, as is the case with psychotics, this may simply be due to more jumps made by these two classes, and until more definite data is available concerning the relationship between total falls and survived falls this must remain unknown.

Presentation of further objective data is obstructed by the inconclusive nature of the medical evidence in such cases. While the medical history may contain a statement by the physician that the individual was intoxicated at the time of the fall, and this may be subjectively verified by police or other witnesses, no blood tests were taken on any of the reported cases. Similarly, other cases of survived free-falls might have involved a degree of intoxication not reported. In only one case, that of a young male who jumped from the roof of a hotel, is concrete evidence available. In his case two witnesses kept track of the 60 ounces of scotch and milk (he had an ulcer) he consumed in the two hours preceeding the fall.

Thus one factor which may be common to both the intoxicated individual and the mentally disturbed, which has most often been reported as paranoid schizophenia, concerns the effect upon the neuro-muscular system. Since previous studies have demonstrated the importance to impact tolerance of muscle tonus, there is substantial basis for considering this factor in the high survival rate among individuals abnormally relaxed in either or both of these conditions.

VIII. Age and Sex

Chronological age in the study population ranged from 1½ to 91 years, and included 104 males and 33 females. As is shown in Figures 5 and 6, age must be considered a factor in free-fall due to the distribution of falls. Since only 131 cases of the study population are compared as to age, and there represent a selected group, the first 3284 cases of survived free-falls in our files were plotted for comparison and as a check on randomness of the selected samples. These falls, representing 544 females and 2740 males, occurred during part of the same time period as the selected falls. Reference to Figure 5 shows an interesting comparison between male and female falls.

In general the highest incidence of survived free-falls occurs in childhood, sharply dropping off by the teens. However an interesting difference is indicated between incidence of male and female falls, with females having many more falls to age 19, and males having more falls in every age group from 20 to 65 years. After age 65, females have proportionately more survived free-falls than males. The study population, even though a selected one, contains less individuals in the 10-19 age group, and more in the 20-35 age group, than the larger population. However, it otherwise follows quite closely the expected proportions.

Figure 6 compares the incidence of survived free-falls in childhood for the study sample, and 268 females and 671 males from the first 939 falls in our files.

Children, particularly from 1 year of age, when they have started to experiment with bipedal locomotion, to age 4, appear to be involved in a disproportionate number of falls. Females, particularly at age 2, have an incidence of falls proportionately greater than males at every age from 1-12, if considered in relation to total life span. The lower chart plots incidence of survived free-falls from age 1-12 as 100%, and while females in this group have the highest peak (at 2 years), the relationships change somewhat as female falls drop sharply and a rise in male falls occurs from age 8 to 12. Reasons for these differences are probably reflected in changing interests and social role. As girls pass from childhood into adolescence and adult status, exposure to environments conducive to falls also diminishes. Probably the higher incidence of male falls from the teens to age 65 simply reflects the difference in occupational hazards. A more detailed study of age and sex relationships to incidence of free-fall will soon be possible. Analyses of over 10,000 survived cases are cur-

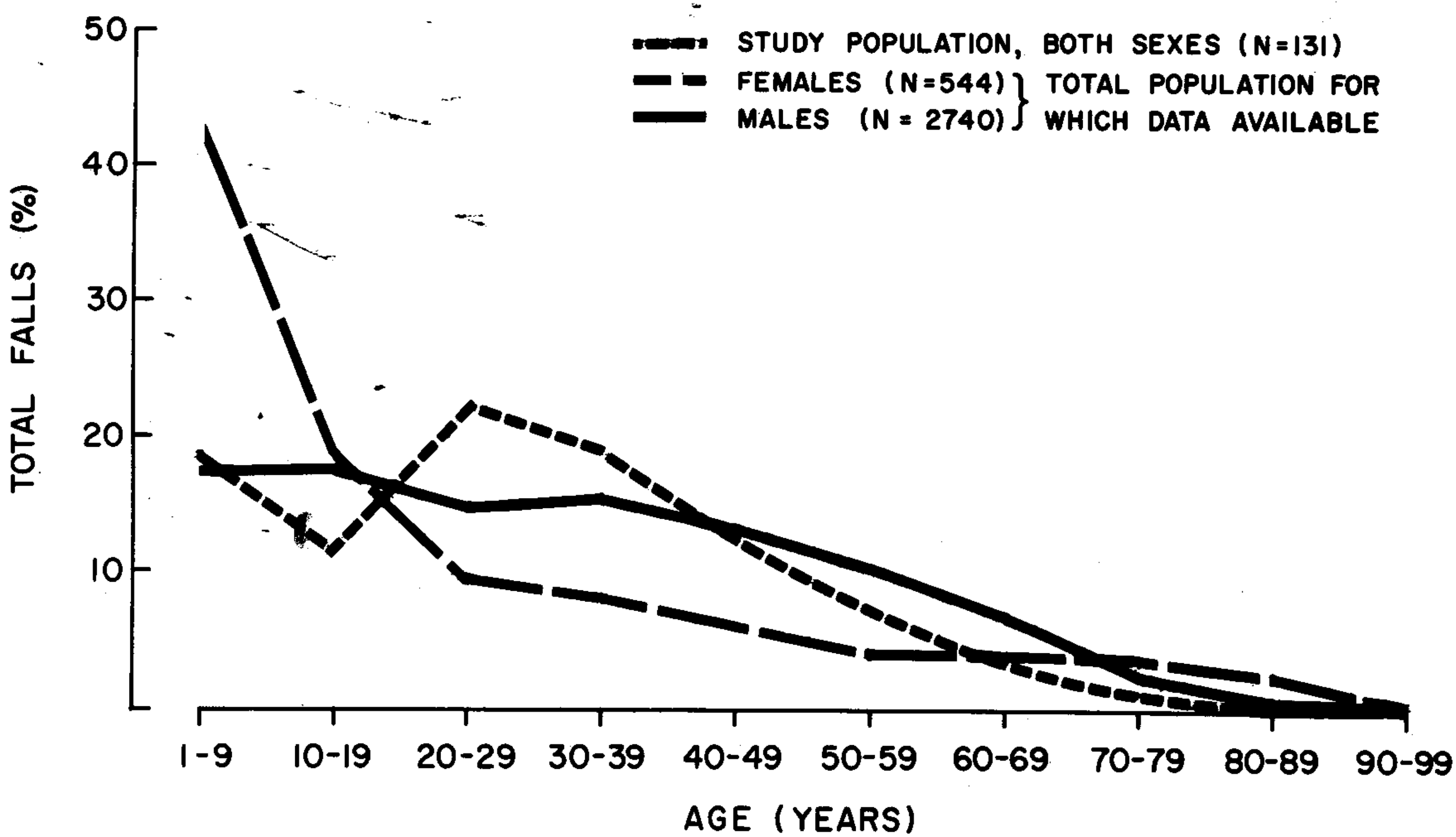

FIGURE 5. Incidence of Survived Free-Falls by Age & Sex.

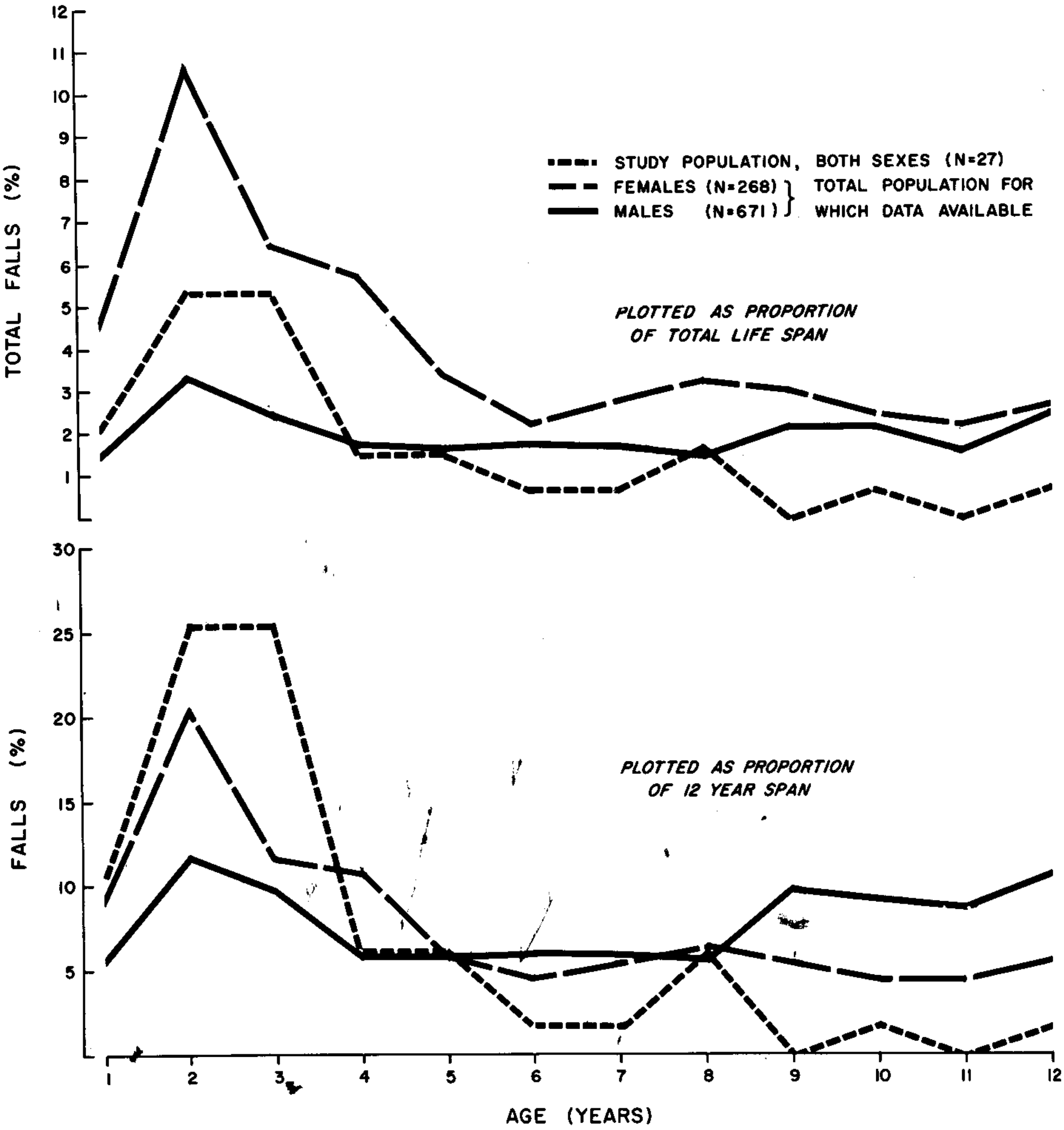

FIGURE 6. Incidence of Survived Free-Falls During Childhood by Age & Sex.

Age	Sex	Distance Fallen	V(ft/sec)*	Body Orientation	Material Impacted	Injuries
1½	M	42'	51	$+G_z$ (feet first)	soil	NONE
1½	M	25'	40	$-G_z$ (head first)	concrete	cerebral concussion
1½	M	17'	32	$-G_z$ (head first)	concrete	fractured skull
2	M	62'	61	$-G_z$ (head first)	concrete	chest contusion cerebral concussion possible fractured skull
2	M	15'	30	$-G_z$ (head first)	concrete	contusion only
2	M	20'	35	$-G_z$ (head first)	concrete	possible fractured skull
2	M	25'	40	$-G_z$ (head first)	snow	NONE
**2½	F	35'	47	$-G_z$ (head first)	concrete	basilar skull fracture
2½	M	24'6"	40	$+G_z$ (feet first)	concrete	NONE
2½	M	18'6"	35	$-G_z$ (head first)	concrete	oblique fissure fracture, right parietal; cerebral concussion
3	F	19'6'	35	$+G_z$ (feet first)	concrete & soil	NONE
3	F	10'4"	25	$+G_z$ (feet first)	concrete & soil	NONE
3	M	21'3"	36	$+G_z$ (feet first)	sandy soil	NONE
3	M	14'	29	$-G_z$ (head first)	hard soil	cerebral concussion periorbital hematoma contusion right eye contusion upper lip
3½	F	18'6"	35	$-G_z$ (head first)	concrete	cerebral concussion fractured skull
3½	F	50'	55	$+G_z$ (feet first)	hard soil	hematoma, right occipital area
3½	F	28'	41	$-G_z$ (head first)	hard soil	cerebral concussion; severe contusion, left shoulder; fracture lamina bilateral C-1; fracture lamina bilateral C-2.
4	F	23'	38	$+G_x$ (hands & knees)	macadam walk	sprain, right ankle; laceration, chin
4	F	31	44	$+G_z$ (feet first)	soil	NONE

* calculated V (See Chart 7)

** A year earlier fell 20' from second story of same building without injury

TABLE V Impact Injuries Received by 19 Children from 1½ to 4 Years of Age.

rently being conducted. It will also be of interest to examine the statistical characteristics of fatal vs. survived free-falls in these age groups.

From these data it appears that children, particularly from age 1-4, are involved in, and may survive, considerably more free-falls than during any other age period. In addition, there seems to be distinct evidence that children in this age group receive less (clinically diagnosed) trauma than when older.

These findings may, however, be artifacts in that children may receive injuries (particularly brain or neurological trauma) not immediately apparent, but which insidiously show up at a later time. On the other hand anyone associated with children has often observed their evident ability to attenuate impacts which might disable those of us more physically mature. Undoubtedly among many physical reasons for child survival of free-falls is the fact that their cartilaginous skeletal structure at this age is relatively flexible (and not rigid or brittle), their proportion of subcutaneous fat is greater than in the adult (and females have thicker subcutaneous fat than males) (39), thereby providing greater protection to internal structures. Muscle tonus is also relatively more relaxed in the younger ages.

However, as with adults, this appears to be greatly dependent upon other factors, especially body orientation at impact. The following table outlines 19 free-falls studied involving children from 16 months to 4 years.

Despite the many factors involved in each case, a comparison of feet first ($+G_z$) and head first ($-G_z$) impacts shows a great difference in injury depending upon body orientation at impact. Although this may be as expected, it is interesting to note that 6 of the 8 children involved in $+G_z$ impacts received no discernible injury and the other two received only relatively superficial injuries, despite impact velocities up to 55 ft/sec (37.5 mph). Only 1 individual out of 11 was uninjured in a $-G_z$ impact.

IX. *Other Factors*

1. *Race*

While racial or ethnic heritage per se may not be a factor in survival of impact trauma, the possibility should not be eliminated on the basis of present evidence. Members of some groups are renowned for their climbing skill. For example, the Mohawk Indians from upper New York state have a legendary reputation as fearless high steel construction workers, more than 100 working in New York City alone (7). Many Louisiana "Cajuns" work on the off-shore oil rigs. But whether training is involved rather than inherent characteristics is unknown, as is the factor of incidence of exposure, which may provide a statistical pitfall. It has been shown that certain groups have acclimated to cold exposure, heat, and other environmental conditions. It is suspected that certain physical types can withstand radiations such as microwave radiation with greater tolerances. Thus certain groups may have superior impact tolerances, but at this point no racial factor, in the biological sense, can be identified. The cases to date include 2 Mongoloids, 16 Negroids, and 119 Caucasoids.

2. *Secondary Impacts*

Many injuries occur upon impacts subsequent to the initial impact. This is particularly true of $+G_z$ impacts in the feet-first body orientation. In this case, one typical sequence seems to be impact on feet → buttocks → back → head, in which the ankles may be initially fractured, compression lumbar vertebra fracture might occur when the seat strikes the ground, and head injuries, such as a subdural hematoma, occur in a third or fourth phase of the total impact. This probably occurs more often than is realized, particularly on certain types of impacted materials having high resiliency. For example, Case No. 2038, a 15 year old youth, dropped feet-first 50 feet onto manure, bounced, landed on his side and fractured a wrist in the secondary impact.

3. *Meterological Conditions*

In any fall occurring in outside environments there are a number of factors associated with the weather that can greatly influence survivability. Rain or snow, for example, may cause a slippery condition resulting in a fall, but may also act to soften a ground impact considerably and thereby result in less injury.

Several construction workers have recently been blown from high girders by winds. Winds are also important in many leaps from bridges – particularly from the Golden Gate Bridge which often has a wind of 5-30 knots–since this force may rotate the body and prevent maintenance of a vertical attitude. The wind may also whip up water, providing a trough and crest wave configuration, along with strong currents. Falls onto icy surfaces mean loss of traction, and the center of gravity condition can result in secondary impacts which might have been prevented on other surfaces. The weather also has a direct influence upon the clothes and footwear being worn and thus may affect fall survival in degree of protection.

DISCUSSION

It is evident from the foregoing that the problem of investigation of free-fall cases is vastly more complex than was initially thought to be the case. Since this is primarily a study of extreme impacts, a high degree of selection was necessary. However, such selection negates the more common statistical design of experiments and requires new techniques for reduction and presentation of data. One would expect, for example, that there would be a high positive correlation of impact velocity with trauma. On the contrary, no such relationship was found. In 78 cases of $+G_z$ feet to head impacts, ranging from 7 ft/sec to 116 ft/sec, the expected injury pattern of fractured ankles is found throughout the series, but in no definite pattern of correlation with velocity. Severe injuries are found at low magnitudes of force, while an apparent lack of trauma is found in cases scattered throughout the impact range.

Other difficulties are presented by the subjective nature of certain information. For example, it is desirable to compare falls occurring from great heights under similar conditions between intoxicated and non-intoxicated individuals. However, while the medical history may often contain a statement by the physician that the individual was intoxicated, no blood tests were taken to substantiate this or indicate the degree of intoxication. Position of impact is a most important factor, and yet people do not always fall in neat x, y, z planes. In fact, even in the feet-first position, they often impact one foot first. In the seated position, the angle of impact may vary greatly, and thus result in different trauma. It is also very evident that a free-fall impact may often consist of a series, or number of impacts. A common feet-first impact sequence is: feet hit, bounce, buttocks hit, bounce, back hits, and finally head strikes. This pattern can be seen in viewing the resulting injuries. For example, the most common pattern consists of a talus fracture or distal tibia, severe head abrasions and lacerations; the latter occurring secondarily, after the initial impact. It is also very difficult to find either a patient or witness who is able to recall accurately and describe such gyrations, all of which occur in very short time intervals. Careful analysis of injuries, particularly superficial ones, along with examination of tears and impact evidence on clothing can often help overcome such problems.

Despite the problems associated with the study of falls, definitive factual data are accumulating from the study of survived free-falls that are not obtainable through voluntary experimentation. It is believed that this approach is the most realistic means of obtaining information concerning impact trauma in the ranges above that to which human subjects can be voluntarily exposed in the laboratory. It should also be emphasized that the cases presented in this paper represent extremes in the impact continuum, and that man's tolerances to deceleration forces are extremely variable.

The work to date has resulted in case documentation of some individuals who have survived impacts corresponding to several thousand G's. Why some individuals are *not* fatally injured in certain cases of extreme impact poses a most intriguing question. It is hoped that analysis of a larger body of data will begin to provide some answers.

SUMMARY

Physical and biological data have been presented on 137 of 168 cases of individuals who have survived extremely abrupt impacts in free-falls. Fall distances ranged up to 275′ and

calculated velocities up to 116 ft/sec (79 mph). This population included both sexes with an age range of 1½ to 91 years. A detailed analysis of factors found to affect survivability in free-fall impacts was presented.

It has been shown that humans have survived impact forces considerably greater than those previously believed tolerable. It is suggested that muscular relaxation (as in intoxication or paranoid schizophrenia) may play an important role in reducing trauma in some cases. These data also indicate that, as the duration of impact is decreased below .0006 seconds and zero time is approached, body tissues may not respond as expected and survival of impact forces of normally fatal magnitude may be increased.

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