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16. Abstract

This report reviews the pertinent literature and adds additional evidence indicating that the human brain may be able to tolerate head impact forces in the range of 300 to 400 g's without evidence of concussion or other detectable neurologic sequelae, provided that provisions are made to prevent deformation of the cranium.

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TOLERANCES OF THE HUMAN BRAIN TO CONCESSION

I. Introduction.

A report[1] published in 1965 showed conclusively that the human face and frontal area of the cranium can withstand crash impact forces in excess of 300 g's without lacerations or fractures, provided that the structure impacted has been properly designed to distribute loads over large contour areas of the head and has adequate yield characteristics. Accepting the data given in this report as fact, the question of brain trauma during such severe impacts arises. It is the purpose of this report to review the pertinent literature and to add some additional test data to attempt to answer this question.

A complete review of all the literature concerned with studies of concussion is beyond the scope of this paper. The most extensive standard literature review was written by Denny-Brown in 1945.[2] Since then, a bibliography by Gross[3] published in 1955 lists over 1000 separate research studies in this area and there have probably been as many more in the past 15 years. However, by far the largest portion of this research involved studies of hammer blows or similar impacts on the heads of various animals or cadavers in which the cranium of the test subject was allowed to deform. Numerous authors[4–8] have expressed the opinion that concussion, contrecoup, and more serious brain injuries are a direct result of skull deformation with or without fracture.

On the other hand, Oelker[9] proposed in 1966 that, due to the suspension of the brain in a fluid having approximately the same specific gravity of the brain, it is improbable that any significant relative motion between brain and skull can be obtained for purely translational accelerations in which *the skull is not deformed.*

It is the purpose of this report to discuss these few studies of human tolerance to concussive forces in head impact situations where skull deformation is prevented or largely reduced.

II. Discussion.

In general, three separate areas of research indicate that concussion and brain injury may be prevented or significantly reduced if the skull is not allowed to deform during head impact. Studies of (1) helmet protection, (2) survival in fall cases, and (3) tolerances of the brain to head impacts with the cranium embedded in a cast are presented in the following discussion.

(1) Helmets of numerous designs have been worn by military personnel, motorcycle riders, race drivers, football players, and others. While the details of construction vary, most of them consist of an outer rigid shell to prevent penetration and distribute the force over a larger area, and a crushable liner to better distribute the force over the shape of the head and to slightly lengthen the deceleration time during the crush phase of the liner. Lombard[10] and his co-workers voluntarily tolerated 38–g frontal impacts while wearing helmets without any indication of concussions. He states that he was sure the human head could tolerate much higher impact forces and that the tests were stopped because of local bruising, tension loads on the ligaments or ligamental attachments of the neck muscles, or sharp burning pains in the joints of the cervical vertebrae. In these tests the subject sat in a chair and the head, covered with a helmet, was struck by a 13-pound weight on a pendulum. This technique accelerated the head, but not the trunk, and would not be the same as if the head and trunk were both in motion.

An empirical study by Snively[11] in 1961 of helmeted racing drivers involved in crash decelerations provides more realistic data concerning brain tolerances provided against impact forces by utilizing crash helmets. His technique was to duplicate the depression of the helmet liners of ten race drivers involved in crashes. Crash impact force readings during the duplication testing with an instrumented dummy head ranged from 115 to over 450 g's. "Six of the ten showed liner deflections indicative of head accelerations well over 200G, and three reached values of 450G or more." All drivers survived and detectable neurologic residuals were not noted. Only four men suffered temporary loss of consciousness and of these, three were above the 200 g's level and one was below. Of interest to note, the one suffering concussion under 200 g's had a history of serious head injuries during World War II. In his summary Snively states "Survival limits of localized head acceleration of brief duration in man have been shown to exceed 450 g's."

The author's small contribution to this field of knowledge bears out Snively's work. A helicopter pilot crashed at Fort Sill, Oklahoma, and was thrown forward and slightly to the right over his seat belt (no shoulder harness). His head and helmet struck a solid blow against the upper left corner of the instrument panel (Figure 1) with sufficient force to fracture his helmet (Figure 2). Identical helmets and instrument panels were obtained from Fort Sill and attempts were made to duplicate the fractured helmet utilizing an instrumented dummy head. Figure 3 is an oscillograph tracing of a head impact with sufficient force to produce a helmet fracture similar to that shown in Figure 2. It will be noted that the major decelerative force was a triangular pulse with a 435–g peak, a 5 milliseconds duration, and a rate of onset of slightly over 105,000 g's/sec. The pilot, in this case study, did not suffer a concussion or loss of consciousness. Rawlins[12] states from his studies that the upper limit for rate of onset is 200,000 g's/sec.

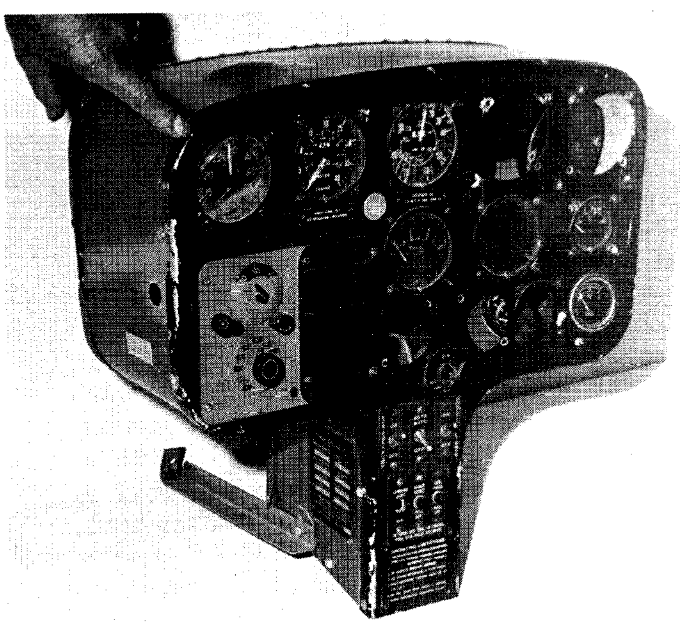

FIGURE 1. Photograph of helicopter instrument panel. Corner impacted by pilot's head is indicated.

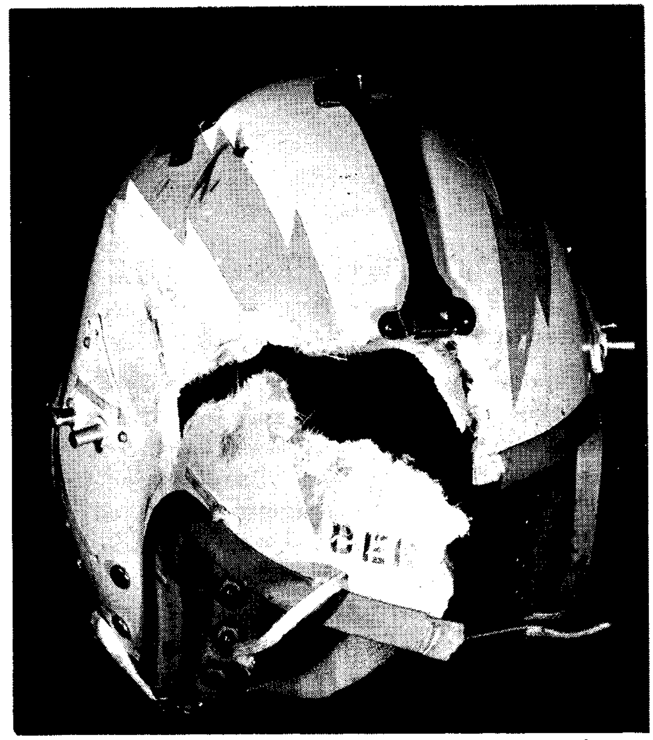

FIGURE 2. Photograph of pilot's helmet showing fracture pattern.

While it has been shown that use of a protective head gear can protect the human head and brain from extremely high impact forces, their protection is limited by the short decelerative distance afforded by the thin helmet liner and the fracture or deformation forces of the outer shell when striking sharp corners, ridges, knobs, etc. In addition, only very small select populations will submit to the use of protective head gear.

(2) Most of the traveling population can better be protected from head injury and/or concussion through the use of materials and engineering design of the cabin environment to distribute forces evenly over large areas of the head and provide proper yield characteristics to lengthen the deceleration time interval.

The extent to which these designs could yield dividends is well illustrated in the early studies of DeHaven[13] and later by Snyder[14] of persons surviving impacts after falls from extreme

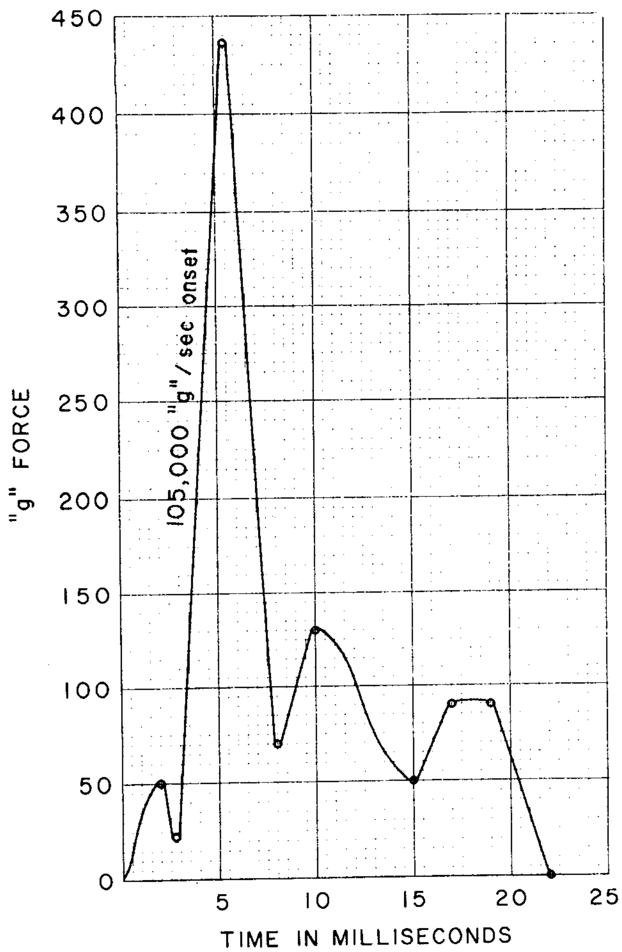

FIGURE 3. Acceleration—time—force curve of head impact necessary to duplicate fracture of pilot's helmet.

heights. DeHaven describes falls of persons in a supine attitude that struck yielding materials (automobiles, metal ventilators, soil) in such a manner as to distribute the force in time and area. In some cases average impact forces of 150 g's (Peak=300 g's) were tolerated without skull fracture, loss of consciousness or subsequent evidence of concussion. Snyder's studies involve large numbers of fall cases and have shown that man can tolerate much higher decelerative forces without concussion or skull fracture.

(3) The only study known to the author in which the cranium was almost completely protected from deformation during impact was done by Higgins[15] using small primates as subjects. Caution must be used concerning the direct transfer of results of animal experimentation in the study of the effects of impact energy upon the cerebral functions of man, as there are marked differences in the relative distribution of mass and in the shape, size, and thickness of the two skulls. Higgins potted the heads of his small primates in metal helmets using plaster of Paris to almost totally eliminate skull deformation during head impact. However, he, like Lombard, fixed the body, and the head impacts accelerated the head away from the trunk. Even under these conditions, the subjects tolerated head accelerations of 1.11 to 1.91 x 10^5 radians/sec.^{2} without gross evidence of damage. Only one suffered concussion with an acceleration of 1.56 x 10^5 radians/sec.^{2}. In terms of g's, the author has calculated these accelerations to range from 361 to 622 g's.

III. Conclusions.

While thousands of research studies have been conducted relative to the subject of human concussion, only a few made any attempt to limit the deformation of the skull. However, these few indicate strongly that the human can withstand crash impact forces of 300 to 400 g's magnitude and possibly greater without concussion or skull fracture provided provisions are made to eliminate skull deformation.

This, in conjunction with the author's work concerning facial tolerances, indicates that all lacerations and fractures of the face and cranium, as well as concussion and more severe brain injury, can be prevented during head impacts with forces up to 300 or 400 g's by engineering design to distribute force in *TIME* and *AREA*.

Stated in more meaningful terminology, it appears that it is possible for the human head to tolerate a deceleration from 100 ft./sec. velocity to a complete stop in six inches of travel without lacerations or fractures of the face or cranium and without concussion, unconsciousness, or severe brain injury. However, in view of the limited data used in this report, experiments should be conducted to verify the conclusions indicated in this study.

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