ECCENTRIC HEAD-BOARD IMPACT IN ICE HOCKEY

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The purpose of this study was to investigate into the physical processes taking place upon impact when a hockey player wearing an approved hockey helmet was forced into an eccentric head impact with the boards.

INTRODUCTION

Protective helmets should receive more attention than any other piece of equipment in sports where there is a high risk of head impact. The task of designing adequate and effective headgear for a specific sport includes (a) a definition of the impact environment in quantitative physical terms, (b) a determination of human brain tolerance with respect to the impact environment, (c) an analysis of the physical processes taking place at impact, (d) the development of a device or a system to be placed between the player's head and the impact environment in order to bring it to tolerable level, and (e) an evaluation of the effectiveness of that device or system (Patrick, 1966). One such research program has been undertaken at the University of Sherbrooke, and the present paper was partly based on the results obtained to date.

METHODOLOGY

In order to simulate an eccentric head-board impact and record the processes taking place, a dynamic model was first developed, then measurements of repeated impacts were taken, using appropriate techniques of accelerometry and high speed cinematography.

The development of the dynamic model was based on one of the most threatening impact situations likely to occur in hockey, namely head impact with the boards, which can lead to severe head injuries (Chapleau, 1974). Such head impacts with the boards, for instance, are likely to occur when a player skating close to the boards is projected head first on this unyielding surface, as the result of a bodycheck from an opponent, after being tripped, or after a loss of balance.

It is highly improbable that the resulting impact will be directed exactly at the centre of mass of the head, and both translational and rotational motions of the head are likely to be evidenced at impact. Owing to the dynamic properties of the mass moment of inertia of the head with respect

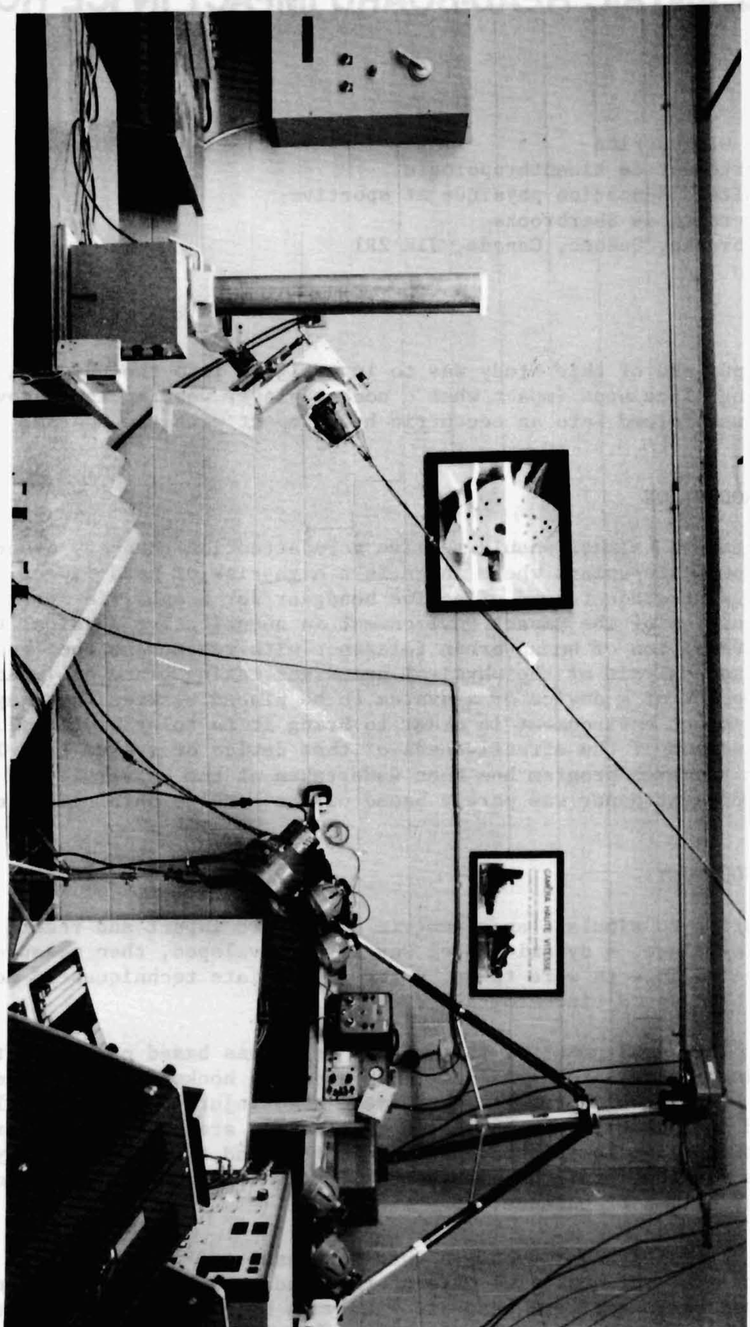

Figure 1: Experimental set up with headform in pre-release position.

to the point of impact, angular acceleration of the head around the impact centre is going to take place at the same time as the centre of mass of the head is experiencing a translational deceleration. The angular acceleration produces a rotation of the skull relative to the brain, while the translational acceleration creates pressure gradients.

The angular acceleration of the skull has been reported to be responsible for the development of considerable tensile forces between the accelerated skull and the inert brain, causing, in turn, shear strains in brain tissues, while linear decelerations of the head have been associated with the compression of the brain particles at the impact site and the expansion of the liquid particles at the site opposite to the impact (counterpole), causing intracerebral haemorrhages and traumatic necroses at the impact pole as well as cavitation trauma and cortical contusions at the counterpole (Unterharnscheidt, 1971). Both of these mechanical behaviours (rotation and translation) have been associated with closed brain injuries either jointly, or separately (Gennarelli et al, 1972). For this reason, the modelled situation included both translational and rotational parameters.

Many approaches can be used in developing a dynamic model of head-board impact. Even though the ultimate realistic approach would involve the actual projection of an instrumented anthropomorphic manikin against ice rink boards, a much simpler model can be developed since the head is totally mass-controlled in impacts of such short duration. In head impacts lasting less than 20 ms, the neck structures have very little influence on the magnitude of both the linear and the angular accelerations of the head upon impact (Schneider et al, 1975). Such a simplified model was developed in the present study, through the use of an instrumented headform pendulum hitting a hockey board in an oblique trajectory (45°) (Figures 1, 2 and 3).

The last step in the development of the model required the selection of input parameters comparable to those of the actual sport situation. Non-professional adult hockey players are capable of maximum skating speed in the range of 28 to 40 ft s^{-1} (8.5 to 12.2 ms^{-1}) (Chao et al, 1973). However, outside of these short bursts of high activity, most of the skating is performed at a speed within the range of 15 to 18 ft s^{-1} (4.6 to 5.5 ms^{-1}). Therefore, head-board impact velocities covered this range. Such velocities (15 and 18 ft s^{-1}) were produced in adjusting the height of release of the headform pendulum according to the desired velocity through the energy conservation equation: $mgh = \frac{1}{2}mv^2$.

In order to record the physical processes taking place at impact, an anthropomorphic headform, previously validated against human head behavior in impact situations, was instrumented with accelerometers positionned in such a way as to obtain, through equations of solid body dynamics, both the linear and the angular accelerations of the headform. Moreover, photographic records of impact phenomena were obtained through the use of a Hicam camera, driven at 6000 frames per second. The camera was located above the board, with its optical axis passing through the impact point.

Prior to experimental impacts, and in order to derive more useful information on the effectiveness of the shock-absorption devices to be interposed between the head and the impact, the headform was covered with two models of

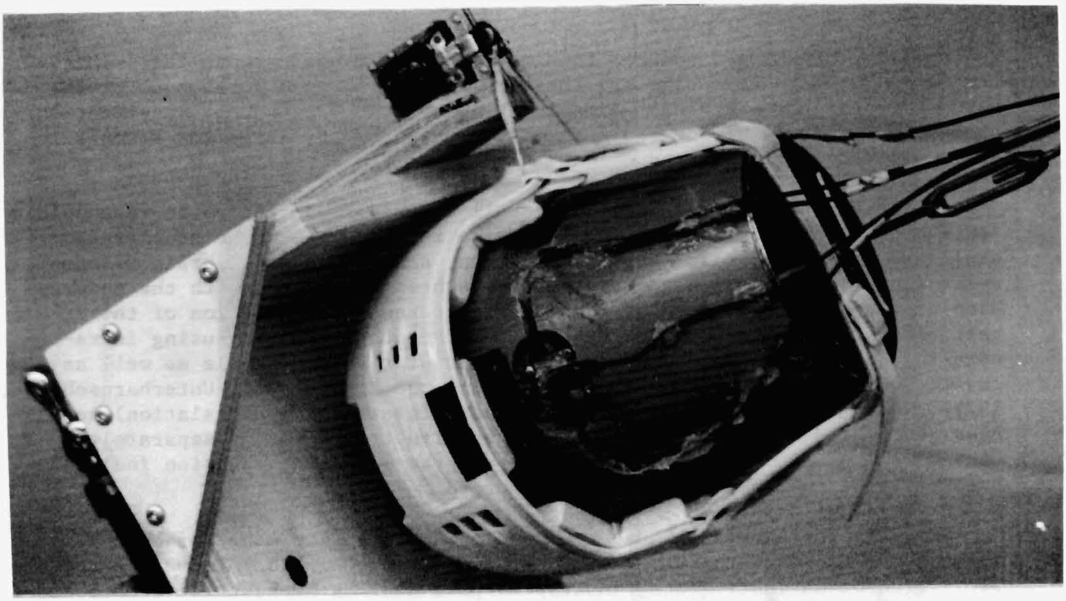

Figure 2: Instrumented headform covered with experimental helmet.

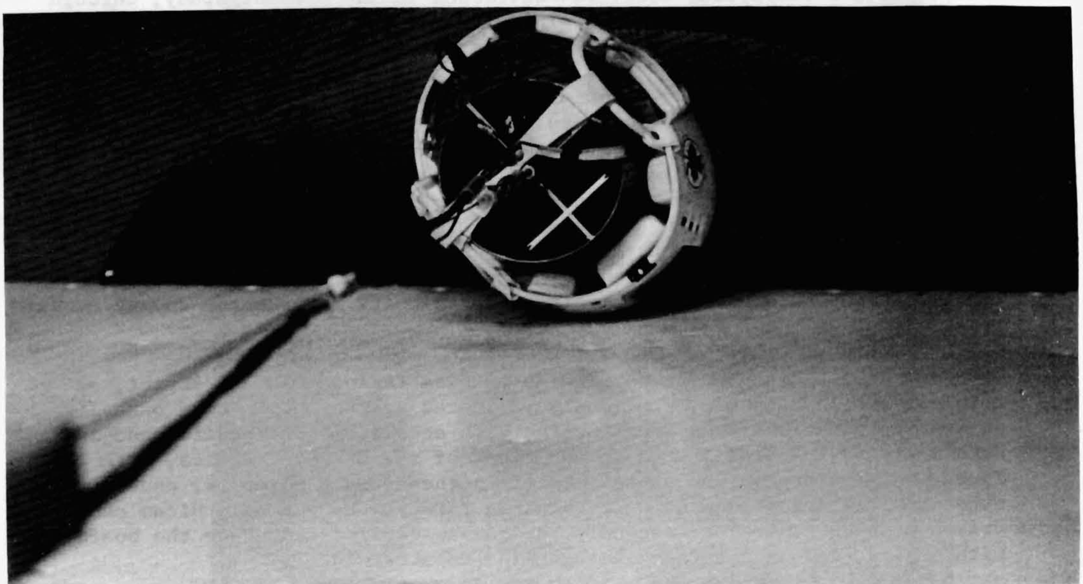

Figure 3: Headform-helmet assembly in board contact position.

hockey helmets. These were CSA-approved helmets, consisting of a one-piece shell design and a shock-absorbing lining on the inside of the shell. One helmet had a strap attachment fixed at two points while the other came with a six-point attachment of nylon straps and buckles, which provided some sliding of the straps when a certain degree of tension was developed.

At the same time as the dynamic model of the impact situation was developed, a selection was made of the criteria governing human tolerance of head impact, to which the experimental results were to be compared.

Even though criticisms have been formulated on the validity and reliability of the different criteria of brain damage due to translational acceleration, the Wayne State University Curve of human tolerance to translational acceleration still remains the cornerstone of the present biomechanical knowledge of human tolerance to this type of brain injury (Newman, 1975; Versace, 1971), and was retained as a first criteria.

In this particular eccentric head-board impact, producing angular motion of the head, the rotational acceleration tolerance curve developed by Sano et al (1972) was a logical choice of brain injury criteria, mostly because of its accordance with experimental data, even if it is more conservative than the criteria proposed by Ommaya and Hirsch (1971).

RESULTS

Quantitative and qualitative analysis were made of the data obtained from 5 impacts for each of the 8 sets of experimental conditions (2 velocities x 2 helmet models x 2 friction levels).

Quantitative analysis of the average accelerations and time values yielded the following findings illustrated on Figs. 4 and 5.

(1) all translational accelerations measured were below the brain tolerance threshold;
(2) all rotational accelerations measured were above the brain tolerance threshold;
(3) a small increase in impact velocity (20 per cent) produced disproportionately high increases (close to 100 per cent overall) in both translational and rotational accelerations;
(4) helmet models had very different impact absorption characteristics which were specific to velocity and friction conditions;
(5) lower headform-helmet friction consistently produced higher accelerations at higher velocity;
(6) experimental results were very consistent within each set of conditions;
(7) peak translational and rotational accelerations were attained 7 to 9 ms after the onset of the pulses;
(8) total duration of translational and rotational accelerations was in the 13 to 15 ms range, depending mostly upon impact velocity.

Qualitative analysis of the high speed (6000 frames s^{-1}) film records showed the following sequence of phenomena to occur during the board impact:

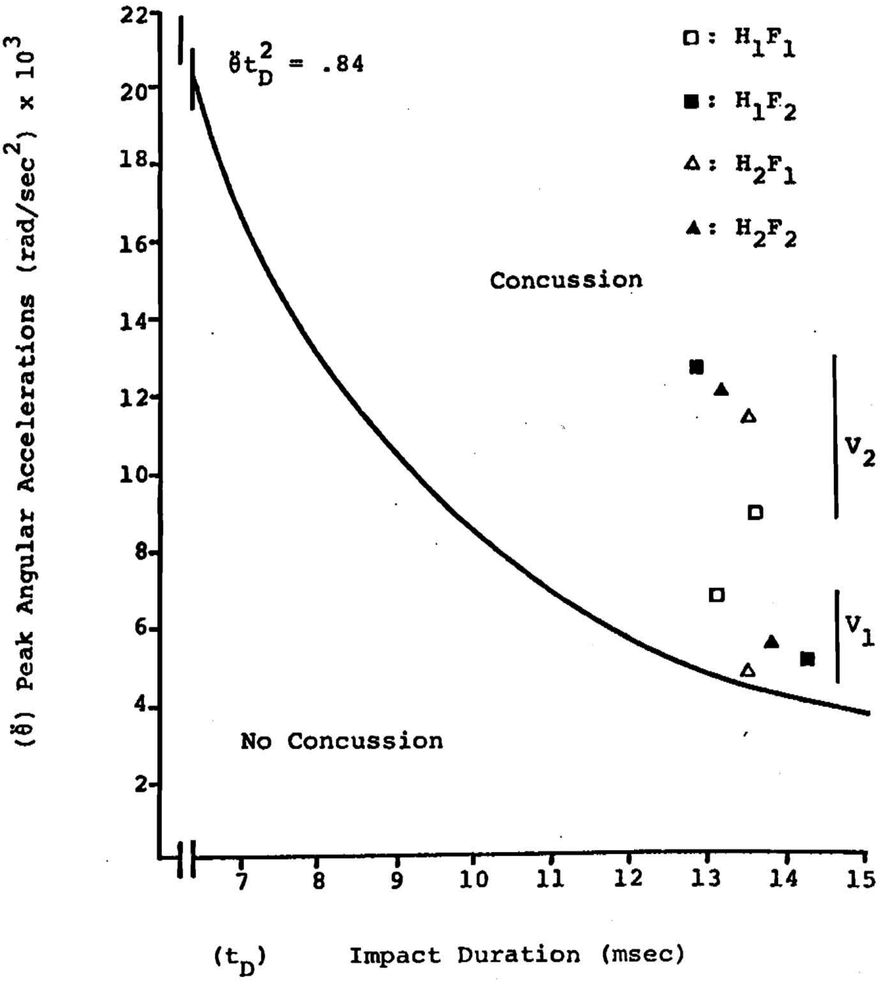

Figure 4 . Plot of experimental angular accelerations on tolerance curve developed by Sano et al (1972).

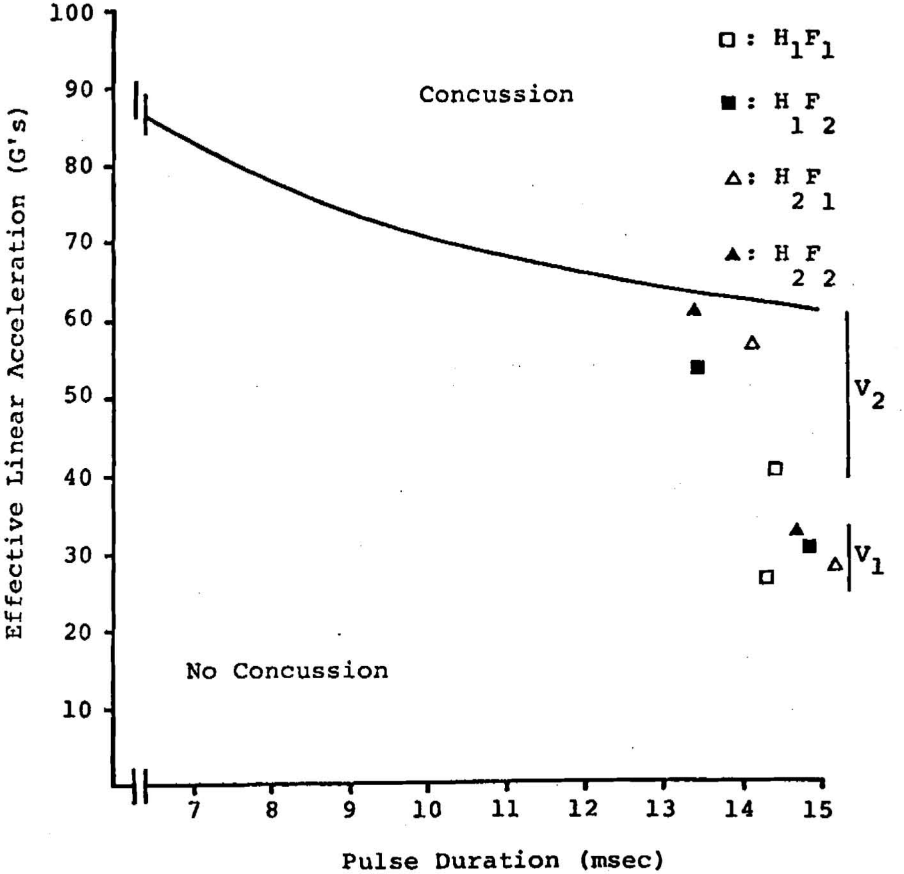

Figure 5 . Plot of experimental linear accelerations on WSU Tolerance Curve.

(1) at the onset of impact the helmet was first deformed in the area adjacent to the site of impact, producing a flattening of the outside shell;
(2) simultaneously, the helmet began to rotate around the headform, while the latter did not yet exhibit any rotation;
(3) after some rotation (5 to 12 degrees, depending upon experimental conditions), the helmet began to regain its original shape, while the rotation of the headform was initiated;
(4) as soon as the headform rotation took place there was no further rotation of the helmet relative to the headform.

This particular behaviour of the helmet rotating around the headform in the first instants of impact suggested that the physical phenomena taking place at the helmet-headform interface may have a close similarity to the motion of the skull relative to the brain, as reported by brain injury researchers to occur in eccentric head impact (Hirsch et al, 1970).

DISCUSSION AND APPLICATIONS

The studies reviewed, the principles of theoretical mechanics, as well as both the quantitative and qualitative information derived from the research programme on ice hockey helmets briefly presented in this paper, allowed some useful applications to the design as well as the selection and use of hockey helmets.

The results presented clearly demonstrated that present-day hockey helmets give a false illusion of protection against severe brain injuries in oblique impact situations: all angular accelerations were above the tolerance threshold to this type of acceleration, while, when using only the translational parameters of the impact, the human tolerance threshold was not attained.

Another indication from the research programme was that, at lower velocity (V_1), a lower friction between the head and the helmet seemed desirable, such as the one produced by a looser attachment or a sliding strap. But at a higher velocity (V_2), it had an opposite effect. This could have a direct application for children whose skating speed is well below 15 ft s^{-1} (4.57 m s^{-1}). In the latter case, a looser helmet (without any exaggeration) would seem to decrease somewhat the angular components of oblique shocks.

Basic mechanical knowledge shows that, if the angular accelerations experienced at impact are dependent upon the moment of inertia of the head-helmet system, then more protection against brain injury is associated with helmets exhibiting lower mass and smaller outside diameter, without losing their ability to absorb the translational components of the impact. This would be even more important for children, who very often are seen wearing very heavy helmets with large outside diameters (due to the extra padding needed to fit the helmets on to their small heads).

However, it is highly improbable that helmet design alone, even if it included some device producing a damping of the rotational motion, could bring the rotational components of high velocity impacts well below the tolerance threshold for humans (Therrien et al, 1982).

Bishop (1976) had already adopted a similar position, and it may well be possible that his proposition of improving all safety aspects of the whole hockey environment is the most effective way of decreasing the rate of brain injuries. This means that the total environment, including boards, glass plates, goals, and especially rules, would have to be changed with one preoccupation in mind: the safety of the player.

Why not make changes in several ice rinks and in a few rules, rather than forcing millions of hockey players to look and often to feel like gladiators!

However, until these changes are performed, most of the protection against brain injury in ice hockey, as well as in other sports which involve a high risk of head impact, will come from improvements in the design and selection of better helmets.

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