AN INVESTIGATION OF THE IMPACT-ABSORBING QUALITIES OF VARIOUS CUSHIONING MATERIALS

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AN INVESTIGATION OF THE IMPACT-ABSORBING QUALITIES OF VARIOUS CUSHIONING MATERIALS

By

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R.H.B.

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CHAPTER I

THE PROBLEM

During the past twenty-seven years there has been a steady increase in the number of fatal head injuries in football. Although the helmet manufacturers realize this startling fact, it is shocking when one considers the small amount of research that has been done in this area. Various cushioning materials are used as liners in football helmets today, largely because of their cushioning appearance and without a thorough knowledge of their impact-absorbing qualities.

Statement of the Problem

It was the purpose of this study to measure the acceleration of cushioning materials and their recovery aspect when struck by an object. This was accomplished by striking each material at various velocities and by repeated blows.

Importance of the Study

Realizing the increase of fatal head injuries in football it is obvious that research is greatly needed in this area. This problem is not a new one. In Marvin A. Stevens' book, The Control of Football Injuries (1933) helmet resdesigning was already being considered because of the increasing head injuries. There was a tendency at that time to make headguards heavier, larger and harder in an attempt to cut down on the increasing head injuries. The result was that they merely became offensive weapons and failed to absorb the shock of blows.[1] Since that time helmet construction has progressed considerably but it is evident by statistical proof, that helmet construction has not kept pace with the speed of the game.[2]

The Twenty-Seventh Annual Survey of Football Fatalities (1931-1958) states that fatalities directly related to football have averaged 17.52 per year, and a total of 473 deaths have been recorded since 1931.[3]

The report further shows that a tabulation of specific location of fatal injuries has been performed by this committee since 1947, and that the head and face areas accounted for 63.80 percent of all fatalities, the spine for 17.68 percent, and abdominal-internal for 18.62 percent.[4]

A further analysis of the data by the location of the blow reveals that spine injuries were caused by blows to the top of the head. Combining these two (head and spine) results in the face that 81.48 percent of all fatalities since 1947 are due to traumatic blows to the head.[5] (See Figure 1.)

In a still closer investigation, the specific location of each blow was reported. The results were:

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[1]Marvin A. Stevens, The Control of Football Injuries (New York: A. S. Barnes and Co., 1933), p. 63.

[2]Committee on Injuries and Fatalities, American Football Coaches Association, Dr. Floyd R. Eastwood, Chairman, Twenty-Seventh Annual Survey of Football Fatalities, January 1959, p. 3.

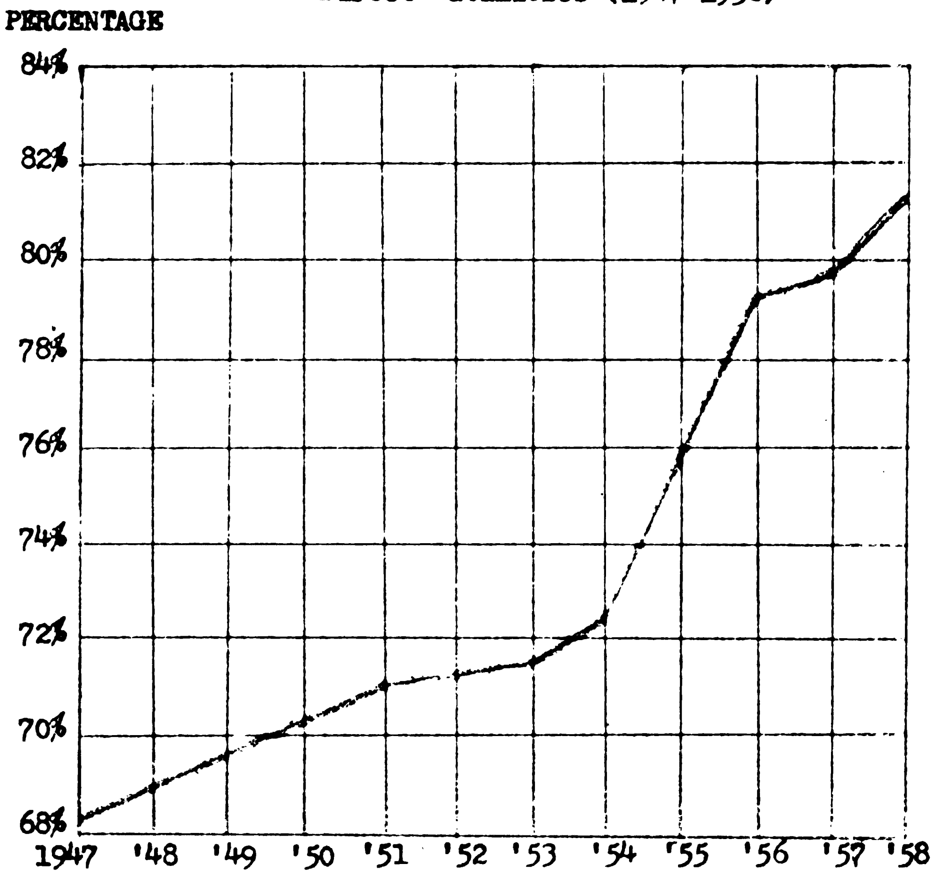
[3]Ibid., p. 3.

[4]Ibid., p. 3.

[5]Ibid., p. 12.

FIGURE 1

Percentage Comparisons*
Head and Spinal Injuries
Direct Fatalities (1947-1958)



*Cumulative Averages based on all fatalities reported yearly since 1931.

> The left and right front and side of the head incur 21.32 percent of all injuries.
> Internal injuries rank second with 18.62 percent.
> Blows to the top of the head (resulting in spinal injuries incur 17.68 percent.
> Traumatic blows to the back of the head incur 13.21 percent of all injuries. (Interpreted this means that the most hazardous areas of the body are ranked: (1) both sides and front of the head. (2) internal organs. (3) top of the head and, (4) back of the head).[6]

As a result of these startling figures continued research is of absolute necessity in this area. What qualities comprise the best and safest helmet have not yet been determined but more and more research is being carried on in this area.

In a letter sent by Dr. Lombard to Dr. Floyd Eastwood in June of 1956, he states his ideas on helmet construction:

> A hard external shell capable of deflecting blows because of its smooth surface and capable of distributing the blow because of its resistance to distortion.
> An energy absorption layer next to the helmet skull, and internal, of not less than 1/2 inch thickness.
> A resilient sizing layer or a sling hatband suspension layer to attenuate the uncomfortable impacts.[7]

Since that time, however, little research has been carried on to determine the best qualities which compose a good impact-absorbing helmet. Some research has been done on football equipment at the Cornell Aeronautical Laboratory, Inc. Various other studies have been done by the Aeromedical Laboratory, School of Medicine of Southern California, Los Angeles; Lombard, et al.; and several Master's thesis have been written on the subject.

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[6] *Ibid.*, p. 4.

[7] Protection, Incorporation, Division P. O. Box 61037, South Station, Los Angeles 61, California. Personal correspondence dated February 9, 1959.

It is hoped through this study on cushioning materials, a contribution can be made to this great need, and the groundwork can be established to find a suitable material, which will help in the reduction of head injuries, through its excellent impact-absorbing qualities.

Limitations of the Problem

This research is primarily to test the impact-absorbing qualities of various cushioning materials. One should realize that even though a material can absorb impact at high velocities there are other factors not undertaken in this test, which must be considered.

Temperature is an important factor. Football equipment is used under many types of weather conditions; therefore, the material should be effective under all temperature conditions.

Another factor to be considered is the proper thickness of the material. At what thickness will the material be most effective?

This study is just a part of the necessary research needed in this area. No final conclusions can be drawn until all available material has been thoroughly investigated and all factors considered.

CHAPTER II

REVIEW OF THE LITERATURE

The review of the literature is divided into three sections. Firstly, the effects of impact on the human head; secondly, cushioning material tests; and thirdly, a section on the qualities of cushioning materials.

Effects of Impact

Medical doctors have a great responsibility in football. If a player is rendered unconscious by a blow to the head, in most cases the player will recover before the doctor examines him. Although he recovers should he be allowed to continue in the contest? This is the decision the doctor faces. Most medical doctors, however, do not realize the fact that the largest percent of fatalities in football are due to head injuries. (See Table 1)

In the Twenty-Seventh Annual Survey of Football Fatalities (1931-1958) it was revealed that fatal accidents have resulted from traumatic blows to the head in 72.25 percent of all injuries.[8] The percentage of total fatal head and spine injuries, due to blows to the head, has increased continually since they were first recorded in 1947. (See Figure 1.)

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[8]Committee on Injuries and Fatalities of the American Football Coaches Association, Twenty-Seventh Annual Survey of Football Fatalities, op. cit., p. 11.

TABLE 1

Direct Fatalities
Specific Location of Injuries
1947-1958°

Part of Body	Sandlot	Pro and Semi Pro	High School	College	Football Official	Total	%
Head Area							
Temple	1	0	0	0	0	1	.53
Front left	3	0	1	0	0	4	2.14
Front right	1	0	5	0	0	6	3.20
Side-left	1	1	11	0	0	13	6.93
Side-right	2	3	11	1	0	17	9.05
Back of head	3	0	21	1	0	25	13.21
Nose and face*	1	0	0	0	0	1	.53
Not specified	19	4	26	4	0	53	28.21
Spine							
Cervical 3rd, 4th, 6th, 7th	2	7	19	3	0	31	16.60
Not specified	0	0	1	1	0	2	1.08
Internal	7	3	19	1	1	31	16.49
Not specified	0	2	2	0	0	4	2.13
TOTALS	40	20	116	11	1	188	100.00

Source–Committee on Injuries and Fatalities, American Football Coaches Association, Dr. Floyd R. Eastwood, Chairman, Twenty-Seventh Annual Survey of Football Fatalities, January 1959, p. 14.

°Tabulation started in 1947.

*Traumatic blow to nose causing rupture of the blood vessels of the neck (one case 1951).

When the head receives a hard blow, it is possible for the following to happen. (1) the skull can be fractured, (2) the brain can be injured, by the force being transmitted through the skull causing a concussion, or (3) both can happen.[9]

Denny-Brown and Russell[10] experimentally produced concussion in animals by striking their heads with pendulums of different masses. Their results proved there were no concussion effects with the lighter pendulum as long as the head was fixed but when it was allowed to move as little as 3 mm. a concussion occurred.

Holbourn[11] in another study on concussions investigated the physical mechanism of brain injury. Holbourn used artificial brain sections of gelatin framed in a paraffin-wax "skull". He found that the maximal strain was produced in the temporal region as a result of rotational accelerations applied to the "skull". This was because the rotating "skull" exerted its strongest force on the brain at the point where the temporal lobe was gripped by the lesser wing of the spenoid. He concluded that the main causes of head injuries were: (1) deformation of the skull with or without skull fracture, and (2) sudden rotation of the head which is probably responsible for concussion.

Lombard, _et al._,[12] designed an experiment to determine the limits

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[9]Edward R. Nye, "Protecting the Head from Impact-Injuries" U.S. Rubber Co., Mishawaka, Indiana. Personal correspondence dated December 10, 1958, p. 8.

[10]D. Denny-Brown, and W. Ritchie Russell, "Experimental Cerebral Concussion", _Brain_, September 1941, p. 93.

[11]A. Holbourn, "Mechanics of Head Injuries," _Lancet_, October 9, 1943, p. 438.

[12]Charles F. Lombard, et al., "Voluntary Tolerance of the Human to Impact Accelerations of the Head" _Journal of Aviation Medicine_, April 1951, p. 111.

of acceleration that a human would voluntarily tolerate, when struck on the head. A pendulum of a mass approximately equal to the head and headgear was used in this study and within its steel head was mounted a strain gauge type accelerometer which was capable of measuring in excess of 500 g. The output from the accelerometer was amplified and fed directly to a cathode-ray oscilloscope tube. The face of the oscilloscope was photographed by a 35 mm. streak camera. For an analysis of the records obtained the 35 mm. films were put into a modified microfilm projector.

The results of these experiments showed that the limit of linear acceleration which the human can tolerate voluntarily, by being hit on the head was not reached when blows as high as 38 G were recorded. The subjects, however, withdrew from higher energy impacts because of bruising, tension loads on the ligaments of the neck muscles, or sharp burning pains in the joints of the cervical vertebrae.

The results of these and other experiments show a definite need for more work to be done in this area, since the majority of deaths to mechanical force in work or play are caused by head injuries. Men of all fields can contribute for a common purpose.

Cushioning Material Tests

The Inland Manufacturing Co., of Dayton, Ohio, participated in a round robin test sponsored by the Society of Plastics Industry to establish a standard test to measure resiliency in plastic materials. The Ball-Drop Resillience Test as it was called, consisted of dropping a 5/8 in. diameter steel ball from an 18 in. height on a piece of material and measuring the rebound of the steel ball. The apparatus consisted of an 18 in. vertical, clear plastic tube, into which a 5/8 in. diameter steel ball was released by an electromagnet. Circles on the tube aided in the visual recording of the ball rebound. The Ball-Drop Resilience is calculated as follows:[13]

$$\text{Ball Drop Resilience} = \frac{\text{Rebound Height}}{18 \text{ in.}} \times 100\%$$

Lombard _et_. _al_.,[14] developed an apparatus to provide dynamic load test data. It consisted of a large block on which the test specimen was attached and a pendulum type hammer containing a strain gauge accelerometer was mounted. The pendulum was released from different heights, thereby striking the material at various velocities. The output from the accelerometer was fed to an oscilloscope which was operated without a sweeping motion. A 35 mm. camera recorded the height of the pip of the oscilloscope.

C. S. Wilkinson[15] of the Goodyear Tire and Rubber Co., developed an electronic pendulum for evaluating the impact absorption of foam materials. The purpose of this study was to measure various foam materials for shock and vibration characteristics. This was done by measuring the deceleration of a physical pendulum. The machine was designed to simulate the conditions present when a person's head strikes the safety pad during an auto collision. Keeping this in mind the shape of the

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[13]Inland Manufacturing Division, General Motors Corporation, Dayton 1, Ohio. Personal correspondence, dated January 14, 1959.

[14]"New Helmet Protection Theory Advanced" (Reprinted from _Aviation Week_, January 24, 1949.

[15]C. S. Wilkinson, "Electronic Pendulum for Evaluating Impact Absorption of Foam Materials" _Rubber World_, September 1957, p. 841.

pendulum used was hemispherical. The design was very flexible, however, to allow different size bobs to be substituted. Impact velocities were in the range of 10 miles per hour. The mechanical design of the machine consisted of a support which was constructed of heavy steel. The pendulum was made of aluminum and was attached to the lower end of a shaft built up of two thin-walled aluminum tubes 48 inches long. Using two tubes prevented the pendulum from being twisted. The upper end of the tubes was fastened to an axle, which rotated in ball bearings. A strain-gauge accelerometer was fastened to the back side of the pendulum to indicate deceleration upon impact. The signal from the gauge was amplified to a dual-beam Tektronix oscilloscope. The penetration of the pendulum into the material was indicated by a transducer built especially for this purpose. After the material had been fastened to the base of support the pendulum was lifted to the proper height and released. Upon impact, the electrical impulses from the transducer were relayed to the oscilloscope. These traces along with the deceleration traces were photographed with a Polaroid type camera to obtain a permanent record.

Cushioning Materials.

Cornell Aeronautical Laboratory, Inc., has done considerable research of cushioning materials, for protecting the head against inflicted blows of various velocities. The results of their tests indicate that the materials which performed the best were the materials having (1) low density, (2) high energy absorbing characteristics, (3) resistance to deformation and (4) adequate thickness.[16]

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[16]Nye, Edward R., op. cit., p. 10.

Density represents the weight of the cushioning material per unit volume, and is usually expressed in pounds per cubic foot.

Materials are classified as either energy storing or energy absorbing. Energy storing material is any material which has complete rapid recovery after impact. Energy absorbing materials are those materials which are permanently deformed when struck. Most of the energy absorbing materials unfortunately are good for one blow and have to be replaced.[17]

An ideal material should have a very low resistance rate. It should be thick enough however, to prevent the head from "bottoming" under the impact.[18]

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[17] *Ibid.*, p. 10.

[18] *Ibid.*, p. 10.

CHAPTER III

METHODS OF PROCEDURES

This chapter is divided into two parts: (1) an explanation of the equipment used in the study, and (2) the design of the experiment.

The Equipment

A strong wooden block was constructed on which the various cushioning materials were attached. This block was connected by two steel cables fastened to the ceiling, and was free to move when struck by an object. The weight of the wooden block was nineteen and three quarter pounds.

A pendulum type weight whose mass was five and thirteen-hundredths pounds was used to strike the cushioning materials. This weight was also attached to the ceiling by means of two steel cables. The striking part of the pendulum consisted of a flat surface.

The pendulum was held at various positions by an electrical release. This consisted of a magnetic coil in which the pendulum type weight was inserted. This coil was turned on and off whenever desired. A small chain, connected to the release box, ran through two pulleys and was fastened with rings to a fixed point on the wall.

The accelerometer used in this study was a Schaevitz linear accelerometer. It was mounted inside the wooden block to record the peak acceleration of the block upon impact.

The output of the accelerometer was fed into a Hewlett-Packard

Model 130A oscilloscope. Mounted on the face of the oscilloscope was a Polaroid camera which photographed the output as it appeared on the scope face. The beam was stopped at various positions on the scope face, making it possible to photograph eight impacts on one photo.

When the velocity was increased, it was sometimes necessary to decrease the sensitivity to keep the height of the pip from going off the screen. A linear relationship existed between the height of each pip and the sensitivity setting, thus, as the millivolts per centimeter increased, the height of the pip decreased.

Twenty-two materials were used in this study. Some of the materials tested are already widely used in athletic equipment. The thickness of the materials were tested as close to one-inch as possible. Half-inch materials were doubled when tested. The following material were tested:

Code Number	Company	Material	Thickness
A	Rubatex Division	G-200-C	1 1/8 in.
B	Rubatex Division	R-300-V	1 in.
C	Rubatex Division	R-313-V	1 in.
X	Rubatex Division	R-310-V	1 1/8 in.
D	U.S. Rubber Co.	Ensolite AL	9/16 in.
E	U.S. Rubber Co.	Ensolite M	1/2 in.
F	Firestone Rubber	Neoprene Slab	1 in.
G	Firestone Rubber	Foamex Slab	1 3/16 in.
H	Dayton Rubber Co.	S-120 M	1 in.
I	Dayton Rubber Co.	S-620	1 in.
J	Dryden Rubber Co.	200-570	1 in.
K	Dryden Rubber Co.	200-555	1 in.
L	Dryden Rubber Co.	250-632	1 1/16 in.
M	Rubber Fabrics Co.	(unknown)	1/4 in.
Q	Koppers Co., Inc.	Polystyrene 1 lb. density	1 in.
R	Koppers Co., Inc.	2 lb. density	1 in.
S	Koppers Co., Inc.	3 lb. density	1 in.
T	Koppers Co., Inc.	4 lb. density	1 in.
U	Blockstrom Co.	Paratex inner laced	1/2 in.
V	Blockstrom Co.	Paratex firm	1 in.
W	Blockstrom Co.	Paratex IV	1 in.
Y	Dow Chemical Co.	Polyethylene	1 1/2 in.

Hereafter throughout the paper, the materials will be referred to by their code numbers.

Experimental Design

The 4" x 4" samples of materials were fastened to the wooden block by rubber bands. Each material was tested twice at the following velocities: six, nine, twelve and fifteen feet per second.

A fatigue test was also made to determine the effects of repeated blows on the ten best materials previously tested. This was done by hitting a sample of each material eighty times. Every tenth blow was recorded and photographed.

Calibration of the accelerometer was made by recording the differerence in levels between the signals when the accelerometer (mounted inside the wooden block) was rotated from a neutral position to one in which the face of the wooden block is parallel to the ground then to one in which the back side becomes parallel to the ground. The difference between the two recordings is equivalent to two times the acceleration of gravity (2 G). This was done before every testing period.

The center of gravity of the wooden block was determined by running a plumb line from one of two attached corners while the opposite corners were unattached and drawing a line where the string fell. This was done for both sides. Where the plumb lines crossed indicated where the center of gravity fell.

It was necessary to find the center of percussion of the wooden block in order to prevent the block from twisting if hit at some other point. The center of percussion was found to be very close to the center of gravity, as was expected. The mass moment of inertia about the point of attachment had to first be determined. This was done as follows:

$$T = 2\pi\sqrt{\frac{k^2}{g\,r}}$$

therefore:

$$k^2 = \frac{T^2 g\,r}{4\pi^2}$$

T = periods of pendulum in seconds.
g = gravity.
r = distance from attachment to center of gravity of block.
k = mass moment of inertia about points of attachment at ceiling.

The following formula was used for determining the center of percussion:

$$g = \frac{k^2}{r}$$

$$g = 8.62 \text{ feet}$$

g = distance from point of attachment to center of percussion.

The center of percussion in our particular case fell above the center of gravity. Normally it should fall below. This was probably due to the difficulty in determining the true pendulum period and because the cables were not directly connected to the ceiling but slanted outward.

After the materials were tested the recordings were measured and were transferred to gravity units. (See Appendix)

The results of the two tests are shown by graphs. The acceleration in G was plotted against velocity in feet per second in the first test. In the fatigue test the acceleration in G was plotted against the number of hits at fifteen feet per second.

CHAPTER IV

THE RESULTS

This chapter is divided into two parts: (1) the results of the impact-absorption test, and (2) the results of the fatigue test.

Impact Absorption

A total of twenty-two materials were tested in the impact absorption test. Each material was hit twice at the following velocities: six, nine, twelve and fifteen feet per second. The mean of the two tests was used for graphing the results. (See Figures 2 and 3.)

In Figure 2 all twenty-two materials are compared through the use of three graphs, thereby giving a clearer picture of the results. In Figure 3 the ten best materials from the impact-absorption test were selected and compared.

As shown by the graphs the peak acceleration of the block increases as the velocity is increased, on all materials. This is to be expected.

The Analysis of Variance technique was employed to determine whether the difference between materials at all four velocities was significant. At all velocities a significant difference was found to exist. (See Table 2.)

The within-groups variance estimate was used as the denominator to determine the F ratio and is referred to as the error variance. This was used to test the significance of the cushioning materials at four velocities.

Figure 2

COMPARISON OF IMPACT CHARACTERISTICS OF ALL CUSHIONING MATERIALS AT VARIOUS VELOCITIES

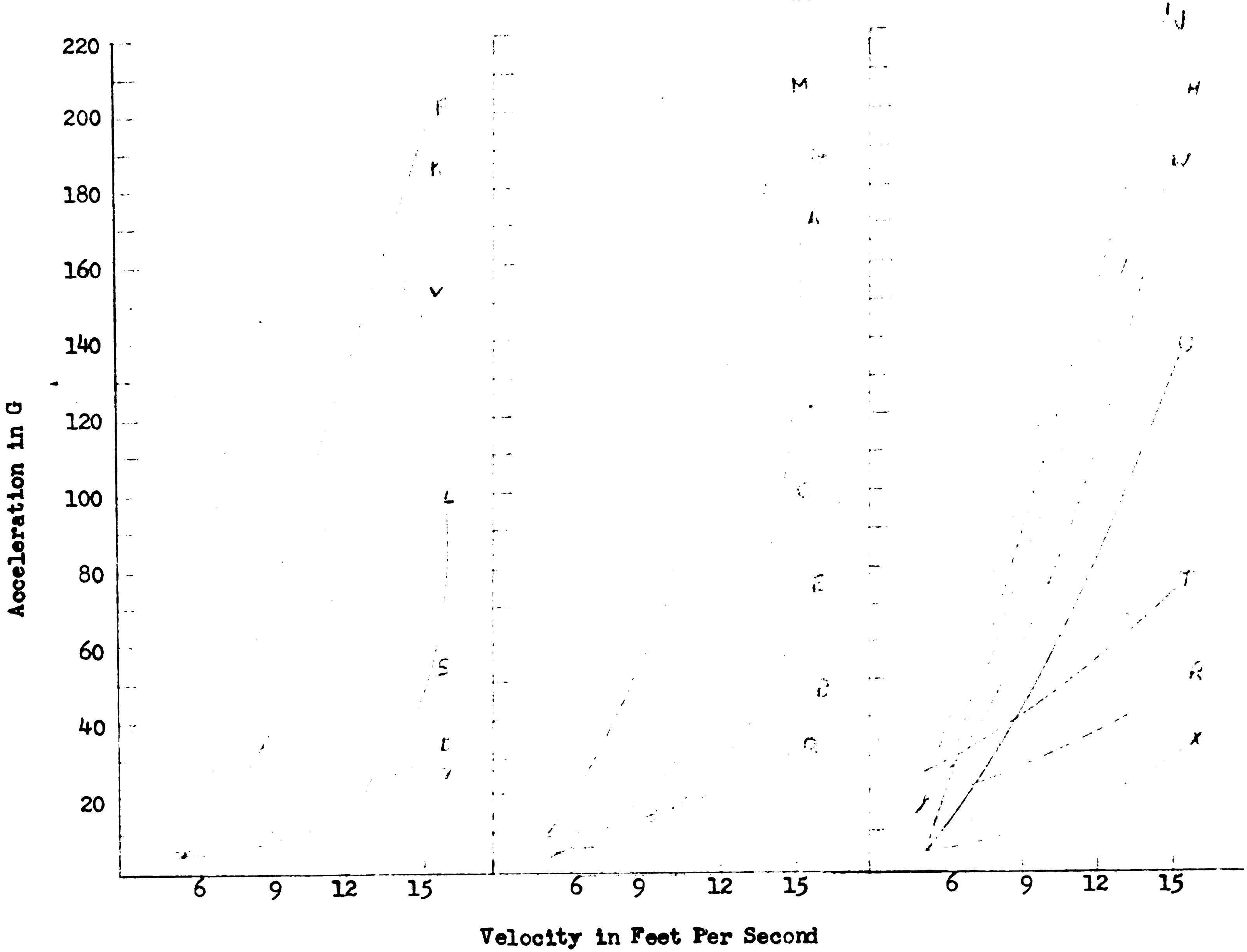

Figure 3

COMPARISON OF IMPACT CHARACTERISTICS OF THE TEN BEST CUSHIONING MATERIALS AT VARIOUS VELOCITIES

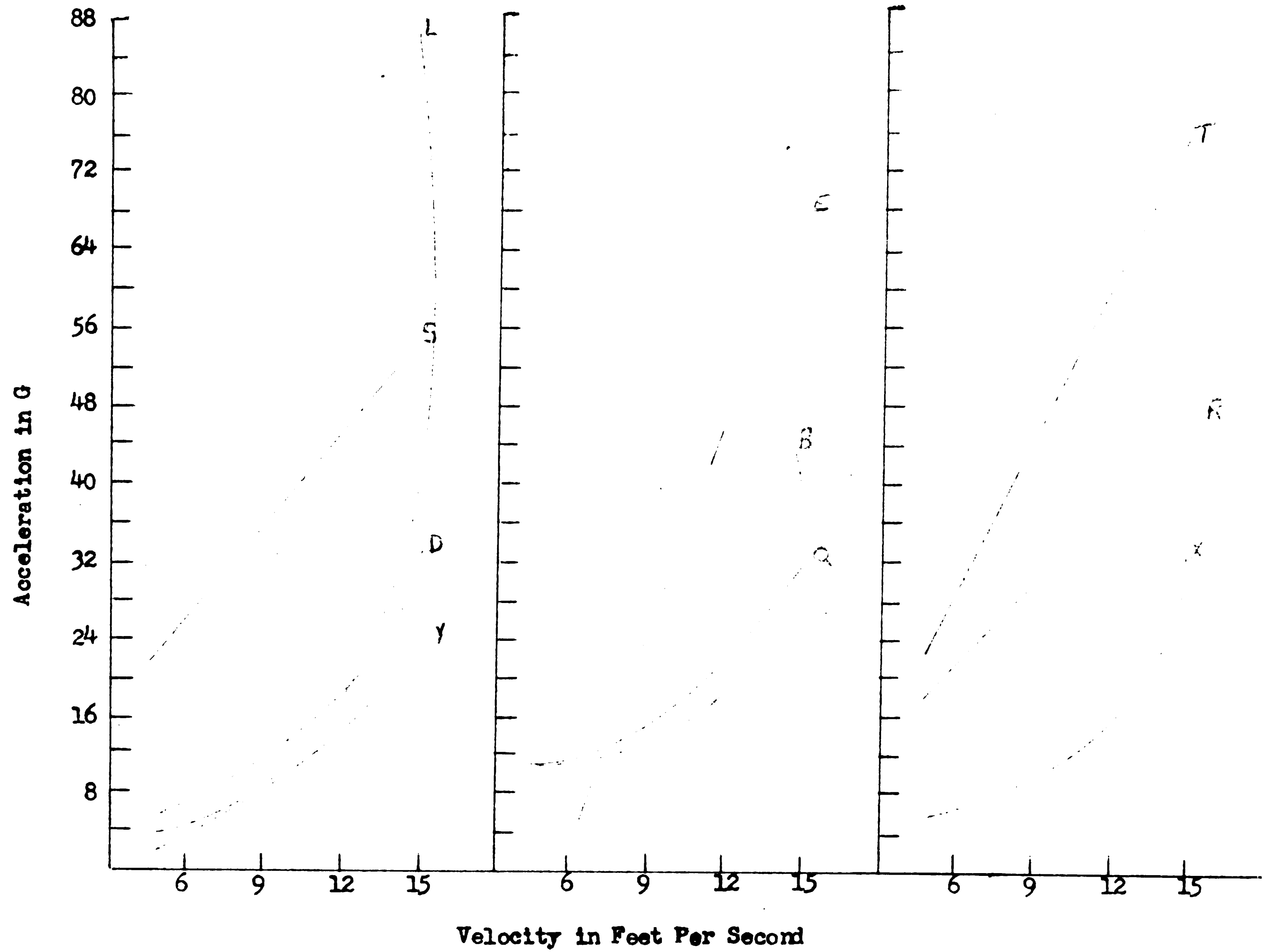

TABLE 2

ANALYSIS OF VARIANCE TABLES
OF CUSHIONING MATERIALS AT VARIOUS VELOCITIES

(Velocity 6 Feet Per Second)

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	
Between	3,392.54	21	161.55	F = 54.58
Within	62.11	*21	2.96	
TOTAL	3,454.65	42		

(Velocity 9 Feet Per Second)

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	
Between	31,324.37	21	1491.64	F = 303.18
Within	108.19	22	4.92	
TOTAL	31,432.56	43		

(Velocity 12 Feet Per Second)

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	
Between	125,349.25	21	5969.01	F = 301.31
Within	435.73	22	19.81	
TOTAL	125,784.98	43		

(Velocity 15 Feet Per Second)

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	
Between	213,000.74	21	10,142.89	F = 461.46
Within	461.50	*21	21.98	
TOTAL	213,462.24	42		

*Twenty-one degrees of freedom exists in the between source because of the insertion of missing data at those velocities.

Fatigue Test

The ten best materials selected from the impact absorption test were used in the fatigue study. These materials included both energy absorbing and energy storing materials.

The energy storing materials were hit at fifteen feet per second impacts, at one minute intervals, for a total of eighty blows. Most of the energy absorbing materials broke after forty blows, therefore, testing was discontinued at that stage. (See Figure 4.)

This test was also repeated and the mean was calculated for graphing.

From the figures one can observe that materials, D, X, and Y are the best three of the previously selected ten. The Analysis of Variance technique was employed between these three materials to determine the following: (1) if the difference in fatigue of these materials was significant, (2) if the materials differed significantly among themselves in relation to fatigue, (3) to determine if the interaction between the three materials and fatigue is significant. In all three cases the F ratios were highly significant. (See Table 3.)

The within-group variance estimate was used as the denominator to determine the F ratio and is referred to as the error variance. This was used to test the significance of the differences between the three cushioning materials, and the fatigue rate among themselves.

Figure 4

COMPARISON OF FATIGUE OF CUSHIONING MATERIALS

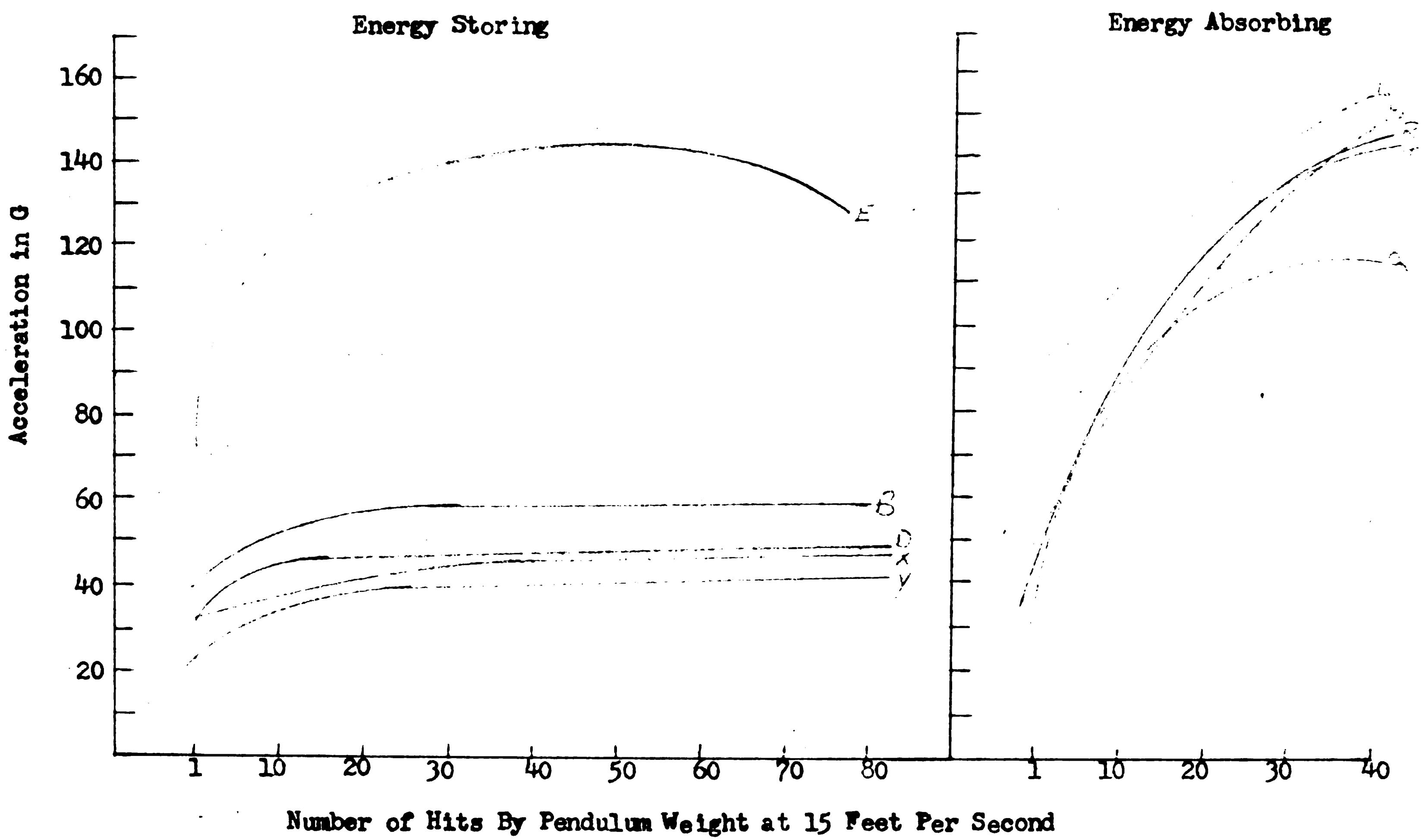

TABLE 3

FATIGUE TEST VARIANCE TABLE

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	
Fatigue	1,111.18	8	138.90	F = 19.21
Material	268.25	2	134.13	F = 18.55
Interaction	3,453.27	16	215.83	F = 29.85
Individual difference within cells	209.62	29	7.23	
TOTAL	5,042.32	55		

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

It was the purpose of this study to measure the impact characteristics of various cushioning materials when struck by an object and to test their recovery aspect. This was accomplished by striking each material at various velocities, and by repeated blows at a fixed velocity.

Two tests were performed on the cushioning materials. An impact absorption test, on twenty-two materials was accomplished by hitting each material twice at the following four velocities: six, nine, twelve, and fifteen feet per second. In testing the materials for fatigue, only the ten best from the impact absorption test were used. Each piece was hit at fifteen feet per second, at one minute intervals for a total of eighty hits. Every tenth hit was recorded.

The cushioning material was attached to a wooden block. Inside the wooden block an accelerometer was mounted. The acceleration upon impact was transmitted to an oscilloscope. On the oscilloscope was mounted a Polaroid camera which photographed the peak acceleration.

The results of both studies were shown by graphs giving an overall comparison of the various materials.

The Analysis of Variance technique was employed in both tests to determine if the results were significant.

Conclusions

1. A review of the literature indicates that the sides of the head incur the greatest percent of head injuries, therefore, they must be adequately protected. This can be accomplished by using the proper kind and amount of cushioning material, and leaving more space for absorbing the blow.

2. Material Y, X, D and B are shown by this test to be the best materials for use as padding in football helmets.

3. Some of the best cushioning materials showing low acceleration under one blow, have a very high fatigue rate, therefore, of little value in football equipment.

4. Various cushioning materials used at the present time as padding in football helmets do not have good impact absorbing characteristics.

Recommendations

1. Cushioning materials should be tested under different types of temperature conditions.

2. The fatigue test should be studied in such a way to determine at exactly what point the cushioning materials "break down".

3. In testing cushioning materials it is recommended that they be of uniform thickness.

4. The thicknesses of the cushioning materials should be varied to see if there is a correlation between performance and conditions.

5. Cushioning materials should be tested more than twice under the same conditions.

6. The pendulum head should be changed in shape to determine how

well the material will perform under different type blows.

7. An accelerometer should be mounted on the pendulum to determine the correlation of the acceleration of the wooden block and the deceleration of the pendulum.

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APPENDIX

MICHIGAN STATE COLLEGE
DEPARTMENT OF PHYSICAL EDUCATION, HEALTH AND RECREATION FOR MEN
GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

TOPIC Cushioning Materials

DATE OF TABULATION April 14, 1959

TABULATED BY Roger H. Borr

	SAMPLE	Thickness	Velocity Ft.per sec.	Date	Hit #1 CM's	Hit #2 CM's	Mean	½ Mean	Vert. Sens.	Sens. CM's	Total CM	G's
1	A	1⅛ in.	6	Ap. 7	4.28	4.08	4.18	2.09	10MV.	2	4.18	4.93
2	A	"	9	"	1.48	1.80	1.64	.82	.1V.	20	16.40	19.35
3	A	"	12	"	4.60	4.59	4.60	2.30	.2V.	40	92.00	108.56
4	A	"	15	"	7.02	—	7.02	3.51	.2V.	40	140.40	165.67
5												
6	B	1 in.	6	Ap. 7	5.39	5.20	5.30	2.65	20MV.	4	10.60	12.51
7	B	"	9	"	.80	.90	.85	.43	.1V.	20	8.60	10.15
8	B	"	12	"	.70	.81	.76	.38	.2V.	40	15.20	17.94
9	B	"	15	"	1.80	1.81	1.81	.91	.2V.	40	36.40	42.95
10												
11	C	1 in.	6	Ap. 7	2.63	2.42	2.53	1.27	20MV.	4	5.08	5.99
12	C	"	9	"	1.00	.98	.99	.50	.1V.	20	10.00	11.80
13	C	"	12	"	1.40	1.88	1.64	.82	.2V.	40	32.80	38.70
14	C	"	15	"	4.00	4.00	4.00	2.00	.2V.	40	80.00	94.40
15												
16	X	1¼ in.	6	Ap. 7	2.59	3.70	3.15	1.58	20MV.	4	6.32	7.46
17	X	"	9	"	.78	.70	.74	.37	.1V.	20	7.40	8.73
18	X	"	12	"	.65	.64	.65	.33	.2V.	40	13.20	15.58
19	X	"	15	"	1.42	1.30	1.36	.68	.2V.	40	27.20	32.10
20												
21	D	9/16 in (2x)	6	Ap. 7	5.70	6.25	5.98	2.99	10MV.	2	5.98	7.06
22	D	"	9	"	4.40	4.72	4.56	2.28	20MV.	4	9.12	10.76
23	D	"	12	"	1.42	1.43	1.43	.72	.1V	20	14.40	16.99
24	D	"	15	"	2.79	2.65	2.72	1.36	.1V	20	27.20	32.10
25												
26	E	½ in. (2x)	6	Ap. 7	2.39	2.40	2.40	1.20	20MV.	4	4.80	5.66
27	E	"	9	"	5.98	5.90	5.94	2.97	20MV.	4	11.88	14.02
28	E	"	12	"	3.80	4.60	4.20	2.10	.1V	20	42.00	49.56
29	E	"	15	"	5.32	5.70	5.51	2.76	.1V	20	55.20	65.14
30												
31												
32												
33												
34												
35												

Calibration (April 7, 1959)
Vert. Sens. 5MV = 1 CM.
Large Beam - Small = 4G's
3.4 CM. = 4G's
1 CM = 1.18G

MICHIGAN STATE COLLEGE
DEPARTMENT OF PHYSICAL EDUCATION, HEALTH AND RECREATION FOR MEN
GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

TOPIC Cushioning Materials

DATE OF TABULATION April 14, 1959

TABULATED BY Roger H. Borr

SAMPLE	Thickness	Velocity Ft. per Sec.	Date	Hit #1 CM's	Hit #2 CM's	Mean	½ Mean	Vert. Sens.	Sens. CM's	Total CM's	G's
F	1 in.	6	Ap. 7	1.40	1.21	1.31	.66	.1V.	20	13.20	15.58
F	"	9	"	5.00	4.94	4.97	2.49	.1V.	20	49.80	58.76
F	"	12	"	5.90	5.90	5.90	2.95	.2V.	40	118.00	139.24
F	"	15	"	3.52	3.22	3.37	1.69	.5V.	100	169.00	199.42
G	1 5/16 in.	6	Ap. 7	1.70	1.60	1.65	.83	.1V.	20	16.60	19.59
G	"	9	"	5.45	5.59	5.52	2.76	.1V.	20	55.20	65.14
G	"	12	"	5.78	5.98	5.88	2.94	.2V.	40	117.60	138.77
G	"	15	"	3.10	3.20	3.15	1.58	.5V.	100	158.00	186.44
H	1 in.	6	Ap. 8	4.40	5.66	5.03	2.52	20MV.	4	10.08	12.60
H	"	9	"	4.41	5.30	4.86	2.43	.1V.	20	48.60	60.75
H	"	12	"	6.09	6.00	6.05	3.03	.2V.	40	121.20	151.50
H	"	15	"	3.25	2.95	3.10	1.55	.5V.	100	155.00	193.75
I	1 in.	6	Ap. 8	2.40	2.98	2.69	1.35	.1V.	20	27.00	33.75
I	"	9	"	7.42	7.08	7.25	3.63	.1V.	20	72.60	90.75
I	"	12	"	6.51	6.32	6.42	3.21	.2V.	40	128.40	160.50
I	"	15	"	3.38	3.45	3.42	1.71	.5V.	100	171.00	213.75
J	1 in.	6	Ap. 8	1.84	2.20	2.02	1.01	.1V	20	20.20	25.25
J	"	9	"	3.49	3.40	3.45	1.73	.2V	40	69.20	86.50
J	"	12	"	6.25	6.60	6.43	3.22	.2V	40	128.80	161.00
J	"	15	"	3.40	3.40	3.40	1.70	.5V	100	170.00	212.50
	"										
K	1 in.	6	Ap. 8	2.55	2.57	2.56	1.28	20MV.	4	5.12	6.40
K	"	9	"	1.50	1.39	1.45	.73	.1V	20	14.60	18.25
K	"	12	"	3.82	3.71	3.77	1.89	.2V	40	75.60	94.50
K	"	15	"	7.37	7.21	7.29	3.65	.2V	40	146.00	182.50

Calibration (April 8 1959)
Vert. Sens. 5MV. = 1CM
Large Beam—Small = 4G's
3.2CM = 4G's
1CM = 1.25G

MICHIGAN STATE COLLEGE
DEPARTMENT OF PHYSICAL EDUCATION, HEALTH
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GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

TOPIC Cushioning Materials

DATE OF TABULATION April 14, 1959

TABULATED BY Roger H. Borr

	SAMPLE	THICKNESS	VELOCITY FT. PER. SEC.	DATE	HIT #1 CM'S	HIT #2 CM'S	MEAN	½ MEAN	VERT. SENS.	SENS. CM'S	TOTAL CM'S	G'S
1	L	1 1/16 in.	6	Ap. 8	3.98	4.50	4.24	2.12	10 MV.	2	4.24	5.30
2	L	"	9	"	2.81	3.01	2.91	1.46	20 MV.	4	5.84	7.30
3	L	"	12	"	1.22	1.41	1.32	.66	.1 V.	20	13.20	16.50
4	L	"	15	"	3.32	3.39	3.36	1.68	.2 V.	40	67.20	84.00
5												
6	M	1/4 in. (4 pc)	6	Ap. 8	1.68	1.61	1.65	.83	.1 V.	20	16.60	20.75
7	M	"	9	"	5.02	5.00	5.01	2.51	.1 V.	20	50.20	62.75
8	M	"	12	"	5.52	5.81	5.67	2.84	.2 V.	40	113.60	142.00
9	M	"	15	"	3.30	3.20	3.25	1.63	.5 V.	100	163.00	203.75
10												
11	Q	1 in.	6	Ap. 8	4.39	—	4.39	2.20	20 MV.	4	8.80	11.00
12	Q	"	9	"	1.20	1.28	1.24	.62	.1 V.	20	12.40	15.50
13	Q	"	12	"	1.60	1.66	1.63	.82	.1 V.	20	16.40	20.50
14	Q	"	15	"	2.54	2.53	2.54	1.27	.1 V.	20	25.40	31.75
15												
16	R	1 in.	6	Ap. 8	1.69	1.60	1.65	.83	.1 V.	20	16.60	20.75
17	R	"	9	"	2.42	2.40	2.41	1.21	.1 V.	20	24.20	30.25
18	R	"	12	"	3.39	3.08	3.24	1.62	.1 V.	20	32.40	40.50
19	R	"	15	"	3.72	3.40	3.56	1.78	.1 V.	20	35.60	44.50
20												
21	S	1 in.	6	Ap. 8	2.19	1.83	2.01	1.01	.1 V.	20	20.20	25.25
22	S	"	9	"	2.97	2.97	2.97	1.49	.1 V.	20	29.80	37.25
23	S	"	12	"	3.81	3.59	3.70	1.85	.1 V.	20	37.00	46.25
24	S	"	15	"	4.40	4.19	4.30	2.15	.1 V.	20	43.00	53.75
25												
26	T	1 in.	6	Ap. 8	2.21	2.35	2.28	1.14	.1 V.	20	22.80	28.50
27	T	"	9	"	3.82	4.08	3.95	1.98	.1 V.	20	39.60	49.50
28	T	"	12	"	5.21	4.30	4.76	2.38	.1 V.	20	47.60	59.50
29	T	"	15	"	5.67	5.60	5.64	2.82	.1 V.	20	56.40	70.50
30												
31												
32												
33												
34												
35												

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MICHIGAN STATE COLLEGE
DEPARTMENT OF PHYSICAL EDUCATION, HEALTH AND RECREATION FOR MEN

GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

TOPIC Cushioning Materials

DATE OF TABULATION April 14, 1959

TABULATED BY Roger H. Borr

	SAMPLE	Thickness	Velocity Ft. per sec.	Date	Hit #1 cm's	Hit #2 cm's	Mean	½ Mean	Vert. Sens.	Sens. CM	Total CM	G's
1	U	½ in (2x)	6	Ap. 10	3.80	4.30	4.05	2.03	20 MV	4	8.12	8.53
2	U		9	"	3.21	2.80	3.01	1.51	.1V.	20	30.20	31.71
3	U		12	"	3.80	3.82	3.81	1.91	.2V.	40	76.40	80.22
4	U		15	"	6.41	6.01	6.21	3.11	.2V.	40	124.40	130.62
5												
6	V	1 in.	6	Ap. 10	.55	.61	.58	.29	.1V.	20	5.80	6.09
7	V	"	9	"	3.67	3.70	3.69	1.85	.1V.	20	37.00	38.85
8	V	"	12	"	4.70	4.10	4.40	2.20	.2V.	40	88.00	92.40
9	V	"	15	"	2.85	2.80	2.83	1.42	.5V.	100	142.00	149.10
10												
11	W	1 in.	6	Ap. 10	2.20	2.21	2.21	1.11	.1V.	20	22.20	23.31
12	W	"	9	"	3.62	3.41	3.52	1.76	.2V.	40	70.40	73.92
13	W	"	12	"	6.10	6.68	6.39	3.20	.2V.	40	128.00	134.40
14	W	"	15	"	3.41	3.38	3.40	1.70	.5V.	100	170.00	178.50
15												
16	Y	1½ in.	6	Ap. 10	1.90	2.10	2.00	1.00	20 MV.	4	4.00	4.20
17	Y	"	9	"	3.52	3.60	3.56	1.78	20 MV.	4	7.12	7.48
18	Y	"	12	"	1.19	1.38	1.29	.65	.1V	20	13.00	13.65
19	Y	"	15	"	2.24	2.20	2.22	1.11	.1V	20	22.20	23.31

Calibration (April 10, 1959)
Vert. Sens. = 1 CM.
Lower Beam - Small = 4G's
3.8 CMS = 4G's
1 CM = 1.05G's

MICHIGAN STATE COLLEGE
DEPARTMENT OF PHYSICAL EDUCATION, HEALTH AND RECREATION FOR MEN
GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

TOPIC Cushioning Material Fatigue Test

DATE OF TABULATION May 1, 1959

TABULATED BY Roger H. Borr

	1st Test Sample	Wt #	CM's	½ CM's	Vert. Sens.	Sens. CM's	Total CM's	G's	Calibration Vert. Sens.	Calibration 10mm=km	2nd Test Sample	Wt #	CM's	½ CM's	Vert. Sens.	Sens. CM's	Total CM's	G's	Calibration Vert. Sens.	Calibration 10mm=km		G Mean	
1	X	10	1.30	.65	.2V	20	13.00	37.18	Ap. 29	1959	X	10	1.20	.60	.2V.	20	12.00	26.96	Ap. 30	1959		27.07	1
2	X	20	1.58	.79	"	"	15.80	45.19	1.40cm=4 G's		X	20	1.38	.69	"	"	13.80	42.50	1.30cm=4G's			43.85	2
3	X	30	1.50	.75	"	"	15.00	42.90	1cm=2.86G's		X	30	1.39	.70	"	"	14.00	43.12	1cm=3.08G			43.01	3
4	X	40	1.60	.80	"	"	16.00	45.76			X	40	1.40	.70	"	"	14.00	43.12				44.44	4
5	X	50	1.62	.81	"	"	16.20	46.33			X	50	1.40	.70	"	"	14.00	43.12				44.73	5
6	X	60	1.62	.81	"	"	16.20	46.33			X	60	1.40	.70	"	"	14.00	43.12				44.73	6
7	X	70	1.62	.81	"	"	16.20	46.33			X	70	1.40	.70	"	"	14.00	43.12				44.73	7
8	X	80	1.63	.82	"	"	16.40	46.90			X	80	1.42	.71	"	"	14.20	4874				45.32	8
9																							9
10	B	10	3.78	1.89	.1V	10	18.90	54.05	Ap. 29	1959	B	10	3.70	1.85	.1V.	10	18.50	56.98	Ap. 30	1959		55.51	10
11	B	20	3.98	1.99	"	"	19.90	56.91	1cm=2.86G		B	20	3.80	1.90	"	"	19.00	58.52	1cm=3.08G			57.71	11
12	B	30	4.20	2.10	"	"	21.00	60.06			B	30	3.80	1.90	"	"	19.00	58.52				59.29	12
13	B	40	4.10	2.05	"	"	20.50	58.63			B	40	3.90	1.95	"	"	19.50	60.06				59.35	13
14	B	50	4.00	2.00	"	"	20.00	57.20			B	50	3.90	1.95	"	"	19.50	60.06				58.63	14
15	B	60	4.40	2.20	"	"	22.00	62.92			B	60	3.80	1.90	"	"	19.00	58.52				60.72	15
16	B	70	4.40	2.20	"	"	22.00	62.92			B	70	3.80	1.90	"	"	19.00	58.52				60.72	16
17	B	80	4.35	2.18	"	"	21.80	62.35			B	80	3.85	1.93	"	"	19.30	59.44				60.90	17
18																							18
19	D	10	1.80	.90	.2V	20	18.00	51.48	Ap. 29	1959	D	10	1.30	.65	.2V.	20	13.00	40.04	May 1,	1959		45.76	19
20	D	20	1.60	.80	"	"	16.00	45.76	1cm=2.86G		D	20	1.30	.65	"	"	13.00	40.04	1.30cm=4G's			42.90	20
21	D	30	1.60	.80	"	"	16.00	45.76			D	30	1.39	.70	"	"	14.00	43.12	1cm=3.08G			44.44	21
22	D	40	1.59	.80	"	"	16.00	45.76			D	40	1.39	.70	"	"	14.00	43.12				44.44	22
23	D	50	1.59	.80	"	"	16.00	45.76			D	50	1.40	.70	"	"	14.CC	43.12				44.44	23
24	D	60	1.70	.85	"	"	17.00	48.62			D	60	1.40	.70	"	"	14.0C	43.12				45.87	24
25	D	70	1.70	.85	"	"	17.00	48.62			D	70	1.40	.70	"	"	14.00	43.12				45.87	25
26	D	80	1.79	.90	"	"	18.00	51.48			D	80	1.40	.70	"	"	14.00	43.12				47.30	26
27																							27
28	E	10	1.80	.90	.5V.	50	45.00	128.70	Ap. 29	1959	E	10	1.65	.83	.5V	50	41.50	127.82	May 1,	1959		128.26	28
29	E	20	1.82	.91	"	"	45.50	130.13	1cm=2.86G		E	20	1.70	.85	"	"	42.50	130.90	1cm=3.08G			130.52	29
30	E	30	2.00	1.00	"	"	50.00	143.00			E	30	1.70	.85	"	"	42.50	130.90				136.95	30
31	E	40	2.10	1.05	"	"	52.50	150.15			E	40	1.60	.80	"	"	41.50	127.82				138.99	31
32	E	50	2.30	1.15	"	"	57.50	164.45			E	50	1.60	.80	"	"	41.50	127.82				146.14	32
33	E	60	2.10	1.10	"	"	55.00	157.30			E	60	1.59	.80	"	"	41.50	127.82				142.56	33
34	E	70	2.00	1.00	"	"	50.00	143.00			E	70	1.70	.85	"	"	42.50	130.90				136.95	34
35	E	80	1.75	.88	"	"	44.00	125.84			E	80	1.60	.80	"	"	41.50	127.82				126.83	35

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MICHIGAN STATE COLLEGE
DEPARTMENT OF PHYSICAL EDUCATION, HEALTH AND RECREATION FOR MEN
GRADUATE STUDIES AND RESEARCH

TABULATION SHEET

TOPIC Cushioning Material Fatigue Test

DATE OF TABULATION May 1, 1959

TABULATED BY Roger H. Borr

	1st TEST SAMPLE	HIT #	CM's	½ CM's	Vert. Sens.	Sens. CM	Total CM's	G's	CALIBRATION Vert Sens 10mm = km	2nd TEST SAMPLE	HIT #	CM's	½ CM's	Vert. Sens.	Sens. CM's	Total CM's	G's	CALIBRATION Vert Sens 10mm = km	G MEAN	
1	Y	10	4.60	2.30	.05V.	5	11.50	35.42	Ap. 30 1959	Y	10	4.70	2.35	.05V	5	11.75	36.19	May 1 1959	35.81	1
2	Y	20	4.83	2.42	"	"	12.10	37.27	1.30cm = 4G's	Y	20	5.00	2.50	"	"	12.50	38.50	1CM=3.08G	37.89	2
3	Y	30	5.00	2.50	"	"	12.50	38.50	1cm = 3.08G	Y	30	5.20	2.60	"	"	13.00	40.04		39.27	3
4	Y	40	5.10	2.55	"	"	12.75	39.27		Y	40	5.40	2.70	"	"	13.50	41.58		40.43	4
5	Y	50	5.20	2.60	"	"	13.00	40.04		Y	50	5.60	2.80	"	"	14.00	43.12		41.58	5
6	Y	60	5.20	2.60	"	"	13.00	40.04		Y	60	5.60	2.80	"	"	14.00	43.12		41.58	6
7	Y	70	5.40	2.70	"	"	13.50	41.58		Y	70	5.50	2.75	"	"	13.75	42.35		41.97	7
8	Y	80	5.40	2.70	"	"	13.50	41.58		Y	80	5.70	2.85	"	"	14.25	43.89		42.74	8
9																				9
10	L	10	3.79	1.90	.2V.	20	38.00	108.68	Ap. 29 1959	L	10	3.80	1.90	.2V	20	38.00	117.04	May 1 1959	112.86	10
11	L	20	4.22	2.11	"	"	42.20	120.69	1CM=2.86G	L	20	4.60	2.30	"	"	46.00	141.68	1CM=3.08G	131.19	11
12	L	30	4.60	2.30	"	"	46.00	131.56		L	30	5.20	2.60	"	"	52.00	160.16		145.86	12
13	L	40	4.99	2.50	"	"	50.00	143.00		L	40	5.22	2.61	"	"	52.20	160.78		151.89	13
14																				14
15	Q	10	6.42	3.21	.1V	10	32.10	91.81	Ap. 29 1959	Q	10	3.20	1.60	.2V.	20	32.00	91.84	May 6 1959	91.82	15
16	Q	20	7.59	3.80	"	"	38.00	108.68	1CM=2.86G	Q	20	3.70	1.85	"	"	37.00	106.19	1.39cm=4G's	107.43	16
17	Q	30	3.80	1.90	.2V.	20	38.00	108.68		Q	30	4.00	2.00	"	"	40.00	114.80	1cm=2.87G	111.74	17
18	Q	40	4.00	2.00	"	"	40.00	114.40		Q	40	4.20	2.10	"	"	42.00	120.54		117.47	18
19																				19
20	R	10	3.30	1.65	.2V.	20	33.00	94.38	Ap. 29 1959	R	10	2.90	1.45	.2V.	20	29.00	83.23	May 6 1959	88.80	20
21	R	20	4.64	2.32	"	"	46.40	132.70	1CM=2.86G	R	20	3.60	1.80	"	"	36.00	103.32	1CM=2.87G	118.01	21
22	R	30	4.80	2.40	"	"	48.00	137.28		R	30	4.60	2.30	"	"	46.00	132.02		134.65	22
23	R	40	5.60	2.80	"	"	56.00	160.16		R	40	4.80	2.40	"	"	48.00	137.76		148.96	23
24																				24
25	S	10	3.20	1.60	.2V.	20	32.00	91.52	Ap. 29 1959	S	10	3.10	1.55	.2V	20	31.00	88.97	May 6 1959	90.24	25
26	S	20	4.20	2.10	"	"	42.00	120.12	1CM=2.86G	S	20	3.50	1.75	"	"	35.00	100.45	1CM=2.87G	110.28	26
27	S	30	4.80	2.40	"	"	48.00	137.28		S	30	4.00	2.00	"	"	40.00	114.80		126.04	27
28	S	40	5.90	2.95	"	"	59.00	168.74		S	40	4.60	2.30	"	"	46.00	132.02		150.38	28
29																				29
30	T	10	3.50	1.75	.2V.	20	35.00	100.10	Ap. 29 1959	T	10	3.20	1.60	.2V.	20	32.00	91.84	May 6 1959	95.97	30
31	T	20	4.05	2.03	"	"	40.60	116.12	1CM=2.86G	T	20	3.80	1.90	"	"	38.00	109.06	1CM=2.87G	112.59	31
32	T	30	5.00	2.50	"	"	50.00	143.00		T	30	4.50	2.25	"	"	45.00	129.15		136.07	32
33	T	40	5.20	2.60	"	"	52.00	148.72		T	40	4.90	2.45	"	"	49.00	140.63		144.67	33
34																				34
35																				35

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Pocket has: 1 Abstract