SELECTED SAFETY FACTORS: IMPACT AND TRANSMISSION OF IMPACT PROVIDED BY BASEBALL BATTING HELMETS

by

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CHAPTER I

INTRODUCTION

When the batting helmet was first introduced to major league baseball two decades ago, it was received with mixed emotion and even opposition from some of the players it was designed to protect. Today, despite a league rule that a player must wear some form of batting helmet, head injuries still occur. In the last three seasons, such outstanding players as Willie Davis, Sal Bando, and Ron Hunt have had to miss regular season games after being struck on the head by a pitched ball. In two of the cases, the player had to be hospitalized. Tony Conigliaro had his playing career cut short by a head injury suffered in baseball (2). A number of participants in youth league baseball have died from injuries received when hit by a pitched baseball (12). A safer helmet might have prevented these injuries and fatalities. At the present time the safety provided by batting helmets must be questioned.

Justification of the Study

The safety of the athlete should be of primary concern to all involved in the sport. The design and construction of protective safety equipment in sports should therefore be based on sound structural design and effective quality control procedures rather than on the whims of manufacturer and consumer demand. This study attempted to determine the degree of protection that batting helmets provide and to see if that protection is sufficient to meet the demands placed upon them.

Statement of Purpose

The purpose of this study was: (1) to determine if a baseball batting helmet can endure the impact of a pitched baseball at velocities of 50, 60, 70, 80, 90, and 100 miles per hour, (2) to determine how much of this impact is transmitted to the head, and (3) to compare different models of helmets for their qualitites of impact and transmission of impact.

Hypotheses

This study was based on the following hypotheses: (1) that there are differences in the protection provided by various baseball batting helmets, and (2) that the differences are the result of the design and materials used in making the helmets.

Delimitations

This study was delimited to the factors of impact and transmission of impact found when a helmet is struck in the temporal region. Only one helmet of each model (professional and youth) was tested from each manufacturer.

Definitions

In this study the following operational definitions were used.

(1) Safety Factor: whether or not the design and the materials of the helmet ensures freedom from hurt, injury, or loss of life.

(2) Impact: the single instantaneous stroke of the ball against the helmet or the helmet against the ball.

(3) Transmission of Impact: the amount of kinetic energy entering

the headform that is not absorbed by the shell and lining of the batting helmet.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

In this chapter, literature pertaining to baseball batting helmets is presented.

Baseball Injuries

An analysis of injuries among 5,001,422 Little League baseball players conducted by Hale (8) indicated that the incidence of injury was 1.96 per cent, and that based upon exposures the pitched baseball caused the greatest number of injuries. The batter being struck by a pitched baseball resulted in 22 per cent of the injuries reported. Klafs and Arnheim (9) stated that approximately 96 per cent of the injuries in college, high school, and youth league baseball occurred in the arm and hand, leg and foot, and head and neck. They went on to point out that recently there had been several deaths among the younger players, resulting from being struck in the head or the chest with a pitched baseball.

Incidence of Head Injuries

Dickinson (3) reporting on the incidence of head injuries in college football indicated that the temporal region was second in percentage to the frontal region in head injuries received. No data of this type was available in baseball. The nature of the batter's stance, the angle and speed of delivery of the ball, and the batter's initial reaction in attempting to avoid being hit by the ball to expose the temporal region leads to the logical assumption that perhaps the percentage of injuries to the temporal region in baseball may be as high or higher than in football.

Types of Head Injuries

Wolfe (18) pointed out that baseball head injuries are different from those of other sports in that they are high velocity, low mass, type of blows on the skull. Gurdjian (7) found that a high velocity impact will tend to produce a localized depression on the skull. He also pointed out that subdural and epidural hemorrhage may form following head injuries in baseball and football. Rowbotham (15) points out that a small mass traveling at great speed can cause a cone-like indentation of bone which, if it pierces the dura mater, can give rise to traumatic epilepsy. This injury, called local deformation, can go unrecognized unless x-rays are taken. Rowbotham further states that a person struck by a small object such as a golf ball or a cricket ball can suffer from extradural hemorrhage. In this case the original head injury is usually relatively mild and restricted to the temporal region.

Peak Acceleration Levels

Gurdjian (7) using human cadavers, found that a skull would fracture with an expenditure of 400 to 600 inch-pounds of energy. At this level, the average acceleration was 112 G's with peaks of 200 G's. The American National Standards Institute (1) when setting the specifications for protective head gear for vehicular users stated "that any peak acceleration of the protective head gear exceeding 400 G's shall be cause for failure." They further stated, "any peak acceleration of 200 G's with a duration of 2 milliseconds or 150 G's with a duration of 4 milliseconds shall be cause for failure." To meet these standards the helmets were tested on a metal headform similar to the one used in the present study. However, Moon, Beedle, and Kovacic (13) conducted a study on peak head acceleration during football and found that player's heads were hit with blows over 1000 G's repeatedly without injury. In this study, players wore a headband containing accelerometers whose data was transmitted to a telemetry system on the sidelines. The investigators agreed with the American National Standards Institute that 400 G's was a safe level, but felt that it may be too arbitrary and cause rejection of perfectly acceptable football helmets.

Aerodynamics of a Pitched Baseball

Selin (17) in a study of the aerodynamics of a pitched baseball found that the mean velocities ranged from 79 to 100 feet per second for college baseball pitchers in the Big Ten Conference. Ryan (16) stated, "even little league pitchers can throw the baseball as fast as 70 miles per hour." These velocities are not as fast as the 100 miles per hour or faster pitching speeds reported for some major league pitchers but do show that a little league or collegiate pitcher can throw a baseball fast enough to produce a velocity necessary for an injuring force. Ryan also pointed out that the professional helmet currently in use offers only minimal protection.

Quality of Protective Equipment

Both Fagan (4) and Robey (14) contended that all too often the quality of a piece of safety equipment was proportional to its price. They further noted that designs in sport safety equipment did not always follow sound scientific techniques, and that many misconceptions exist about the safety provided by athletic equipment. The greatest of these misconceptions being that low priced equipment provides adequate protection.

Football Helmet Studies

Miller (11) in a study on the impact absorbing qualities of commercially manufactured football helmets, found that of 17 selected helmets tested on a wooden headform, all failed to provide adequate protection against injuries at three sites: the front, the rear, and the lower rear. Kovacic (10) in a similar study using a metal headform found that of 27 helmets that he tested, only three were acceptable. The helmets tested were both ones made by commercial manufacturers and prototypes developed by doctors. The reasons for rejecting 24 of the 27 helmets were: (1) eight for shells that split; (2) seven were too heavy and bulky; (3) six had their suspension collapse; and (4) three had shells that were too flexible. Robey (14) in an analysis of over 4,200 head injuries of high school football players, found that suspension type helmets had a significantly lower concussive injury rate, while padded helmets were associated with a significantly higher rate of concussive injury than any other type of helmet mounting. This held true when both helmet condition and helmet fit were considered.

Standards for Helmets

Despite the fact that helmets sometime fail to give the protection necessary, they are of importance in the prevention of head injuries.

Moon, Beedle, and Kovacic (13) reported that a helmet increased the tolerance levels of the head above that for an unprotected head impacting on a curved or flat surface. Rowbotham (15) stated that in a case of acceleration concussion, anything which will dampen the blow will materially protect the brain. Gurdjian (7) in discussing the padding of helmets found that the thickness of padding could be figured from the weight and velocity of the injury object and that if the velocity were doubled, the padding would have to be increased four times. However, he did not indicate how he arrived at this formula.

Although there have been differences cited concerning the impact absorbing qualities of helmets, and the level of peak head acceleration that is safe, a standard needs to be set for baseball helmets similar to the one for protective helmets for vehicular users. Dr. H. A. Fenner, a noted authority on head injuries who helped to develop the standard for protective vehicular helmets, stated best the need for this type of study:

> Head protection means protection of all heads. It makes no difference whose head is being protected--auto racer, skier, football player or baseball player. Certain design modifications are desirable in various applications, but basic design for energy absorption should be as advanced as the state-of-the-art allows. (5)

Dr. Fenner also stated that any acceleration above 400 G's can cause brain damage and that athletes are exposed to these forces, and therefore adequate protection should be provided by the safety equipment they wear.

Summary

A review of the literature pertaining to baseball batting helmets was presented in this chapter. No studies have been found which attempt to measure selected safety factors of baseball batting helmets.

CHAPTER III

PROCEDURES FOR COLLECTING DATA

Introduction

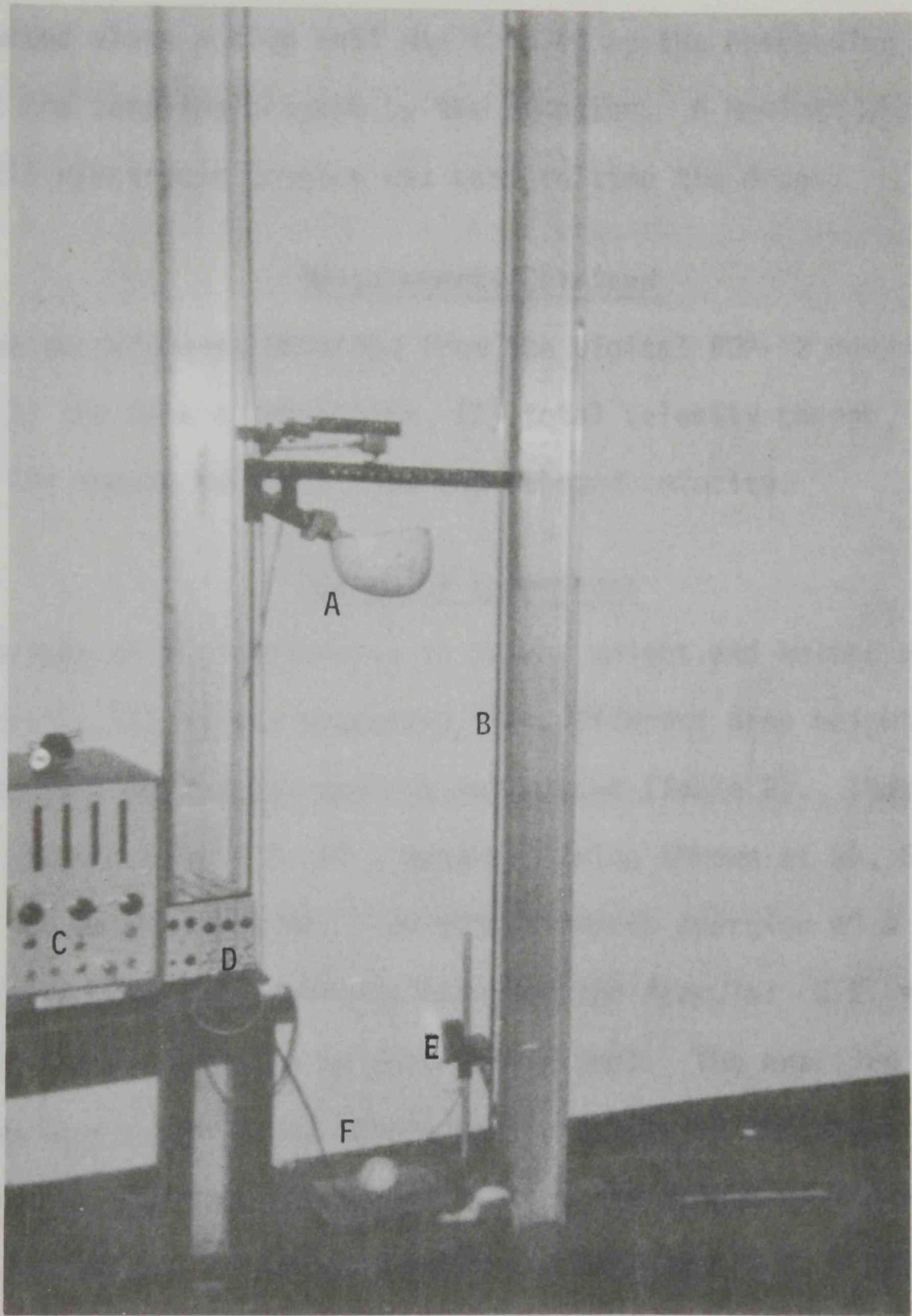
A description of the helmets, instruments for obtaining data, measurements obtained, and design of the experiment are presented in this chapter.

Helmets

The batting helmets used in the study were size 6 7/8 and were of two types as designated by the manufacturers: (1) five helmets were those used in youth league baseball such as little league, and (2) five helmets were those used in high school, college, and professional baseball. The helmets will be referred to as either youth model or professional model throughout the remainder of the study.

Instruments

The aluminum headform and attachments, drop rails, and baseball embedded in a hollowed out block of wood resting on a hard metal anvil are shown in Figure 1. The aluminum headform and attachments weighed 13.59 pounds. The headform was molded so that a size 6 7/8 batting helmet would fit on it securely. An Endevco 2242 accelerometer, which had an output of 1.8 millivolts per G, was built into the headform to give a readout of the amount of kinetic energy (henceforth referred to as K.E.) transmitted to the headform. The accelerometer data went



A. Headform
B. Drop Rails
C. Electronic Counter
D. Charge Amplifier
E. Photo-electric Cell
F. Baseball

Fig. 1.--Test stand, headform, and attachments

through a Brueel and Kjoer type 2624 charge amplifier and then was fed directly into a Digital PDP-12 computer for printout. A photo-electric cell mounted along a drop rail was tripped by the descending headform to start the sampling program by the computer. A Hewlett and Packard model 521A electronic counter was used to time the drops.

Measurements Obtained

The measurements obtained from the Digital PDP-12 computer printout were: (1) the peak acceleration, (2) total velocity change, (3) absorbed energy, (4) impact velocity, and (5) rebound velocity.

Design of Experiment

Because of the difference in helmet weight and helmet and headform weight (Table 1), it was necessary that different drop heights be determined for each helmet for the six velocities (Table 2). These drop heights produced the K.E. of a baseball being thrown at 50, 60, 70, 80, 90, and 100 miles per hour. The actual impact energies of a baseball were computed for each velocity by using the formula: K.E. = $1/2\ MV^2$ (M is mass, V is velocity in feet per second). The energies used in the study were computed by obtaining the height of the drop, which was calculated by dividing the actual K.E. by the weight of the headform and the helmet and inserting it into the formula: K.E. = 1/2 M2GS (S is distance) (Table 3). The headform with attached helmet was raised manually to the prescribed height and secured by a spring-loaded eye bolt. A cord attached to the eye bolt served as the release mechanism for the headform and helmet. After being dropped from the six heights, all helmets that had not failed were retested at the sixth height. Each helmet was dropped until it failed the American National Standards Institute's specifications for protective head gear or up to twenty drops. If a helmet gave some sign of deterioration at the twentieth drop, it was tested until failure occurred.

Some of the procedures and techniques used in this study were adopted and modified from the doctoral study "Shock Absorbing Qualities of Today's Helmets" by Colonel Thomas Rogers of the Industrial Engineering Department, Texas Tech University.

TABLE 1

HELMET AND HEADFORM WEIGHTS

Helmet Code	Helmet Weight (lbs.)	Helmet and Headform Weight (lbs.)
B	.93	14.52
C	.80	14.39
D	.90	14.49
E	.98	14.57
F	.70	14.29
G	1.19	14.78
H	1.29	14.88
I	1.06	14.65
J	1.13	14.72
K	.98	14.57

TABLE 2

HELMET DROP HEIGHTS* FOR SIX KINETIC ENERGIES

Helmet Code	Kinetic Energy					
	25.79	37.48	51.35	66.25	86.91	104.59
B	1.78	2.58	3.53	4.47	5.99	7.20
C	1.80	2.61	3.56	4.61	6.04	7.27
D	1.77	2.59	3.44	4.58	6.00	7.22
E	1.78	2.58	3.53	4.55	5.97	7.18
F	1.80	2.63	3.59	4.64	6.08	7.32
G	1.74	2.54	3.47	4.48	5.89	7.08
H	1.73	2.52	3.45	4.96	5.85	7.03
I	1.77	2.56	3.51	4.53	5.93	7.14
J	1.76	2.55	3.48	4.51	5.91	7.11
K	1.78	2.58	3.52	4.54	5.97	7.18

* Drop heights in feet

TABLE 3

KINETIC ENERGY FOR THE SIX VELOCITIES

Velocity in MPH	MPH Converted to Ft./Sec.	K.E. (Ft.-Lbs.)
50	73	25.79
60	88	37.48*
70	103	51.35
80	117	66.25
90	134	86.91
100	147	104.59

$$\text{Height of drop} = \frac{\text{Kinetic Energy}}{\text{Weight of Headform + Weight of Helmet}}$$

* Example: (Actual) 60 MPH = 88 ft./sec.

$$K.E. = 1/2\ MV^2$$

$$K.E. = 1/2\ (.31/32)\ (88)^2$$

$$K.E. = 37.48$$

(Simulated)

$$K.E. = 1/2\ M2GS$$

$$K.E. = 1/2\ (14.52/32)\ (2)\ (32)\ (2.58)$$

$$K.E. = 37.48$$

Summary

This chapter contained a description of the helmets, instruments for obtaining data, measurements obtained, and design of the experiment.

CHAPTER IV

ANALYSIS OF DATA

Introduction

This chapter contains a description of the data*, the analysis of data, the findings derived from the data, and a discussion of these findings.

Description of Data

The data used in the analysis consisted of the peak acceleration of the helmets, model of helmets, price range of helmets, acceptability of helmets, and absorbed K.E. energy of the helmets.

Analysis of Data

The .05 level of confidence was used for testing the null hypotheses. Analysis of variance with a 2 x 6 factorial design was used to determine if different K.E.'s had an effect upon peak acceleration. The levels for each factor of the treatment phase were the six K.E.'s and two different helmet models. Figure 2 shows the peak acceleration for youth model helmets and Figure 3 shows the peak acceleration for professional model helmets. The summary of the analysis is presented in Table 4.

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* The raw data appears in Appendix A, Appendix B, and Appendix C.

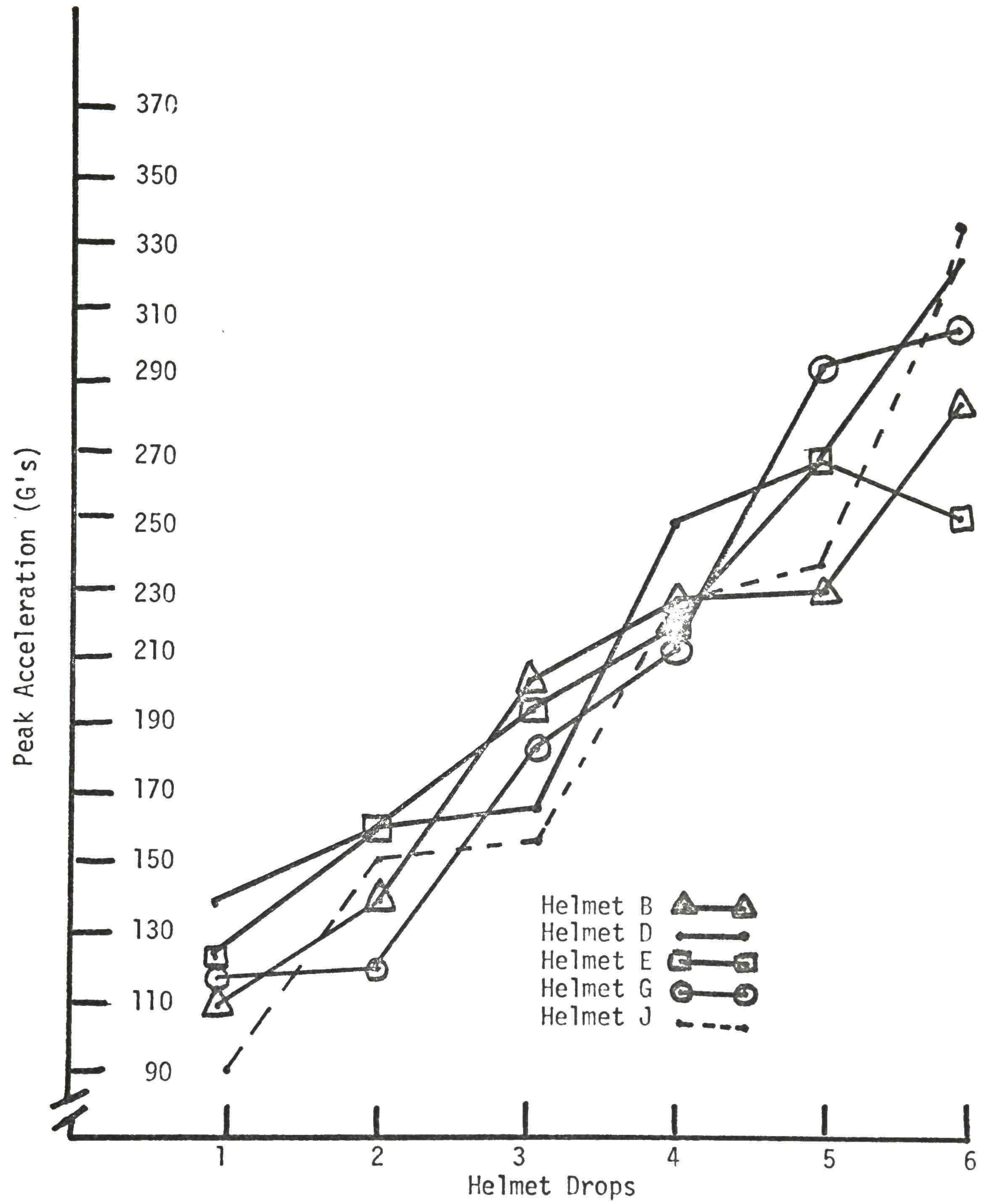

Fig. 2.--Peak acceleration for youth model helmets

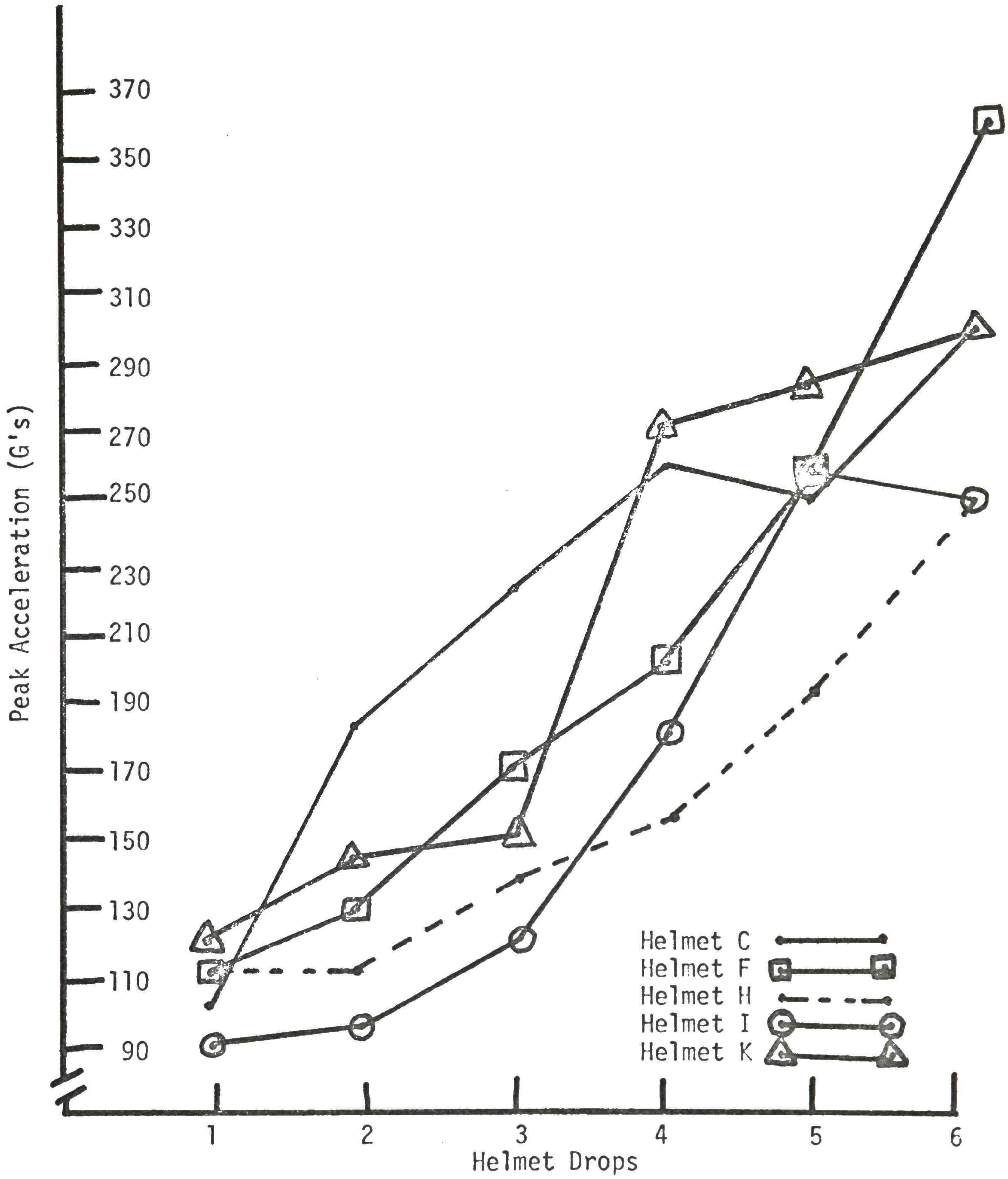

Fig. 3.-- Peak acceleration for professional model helmets

TABLE 4

SUMMARY OF THE ANALYSIS OF VARIANCE

Source of Variance	df	Sum of Squares	Mean Squares	F	Probability
Model of Helmet	1	1498.99	1498.99	1.84	
Drop Heights	5	269537.09	53907.42	66.22	> .05*
Within Replicates	48	39077.64	814.12		
Total	59				

* Significant at the .05 level

The computed F value of 1.84 indicated there was no significant difference between models relative to peak acceleration. The F value of 66.22, however, did indicate that peak acceleration increased in both youth and professional model helmets with the increase in drop height.

Figure 4 shows the absorbed K.E. for youth model helmets for each drop height. Figure 5 shows the absorbed K.E. for professional model helmets for each drop height. As the drop height increased, the total impact energy increased, and therefore the amount of absorbed K.E. increased. Figure 6 shows the percentage of absorbed K.E. of the total impact energy for youth model helmets for each drop height. Figure 7 shows the percentage of absorbed K.E. of the total impact energy for professional model helmets. While Figures 4 and 5 exhibit absorbed K.E.'s curves that are linear in shape, when these absorbed K.E.'s are converted to percentage of total impact K.E. (Figures 6 and 7) the resulting curves exhibit greater variability demonstrating that the helmets

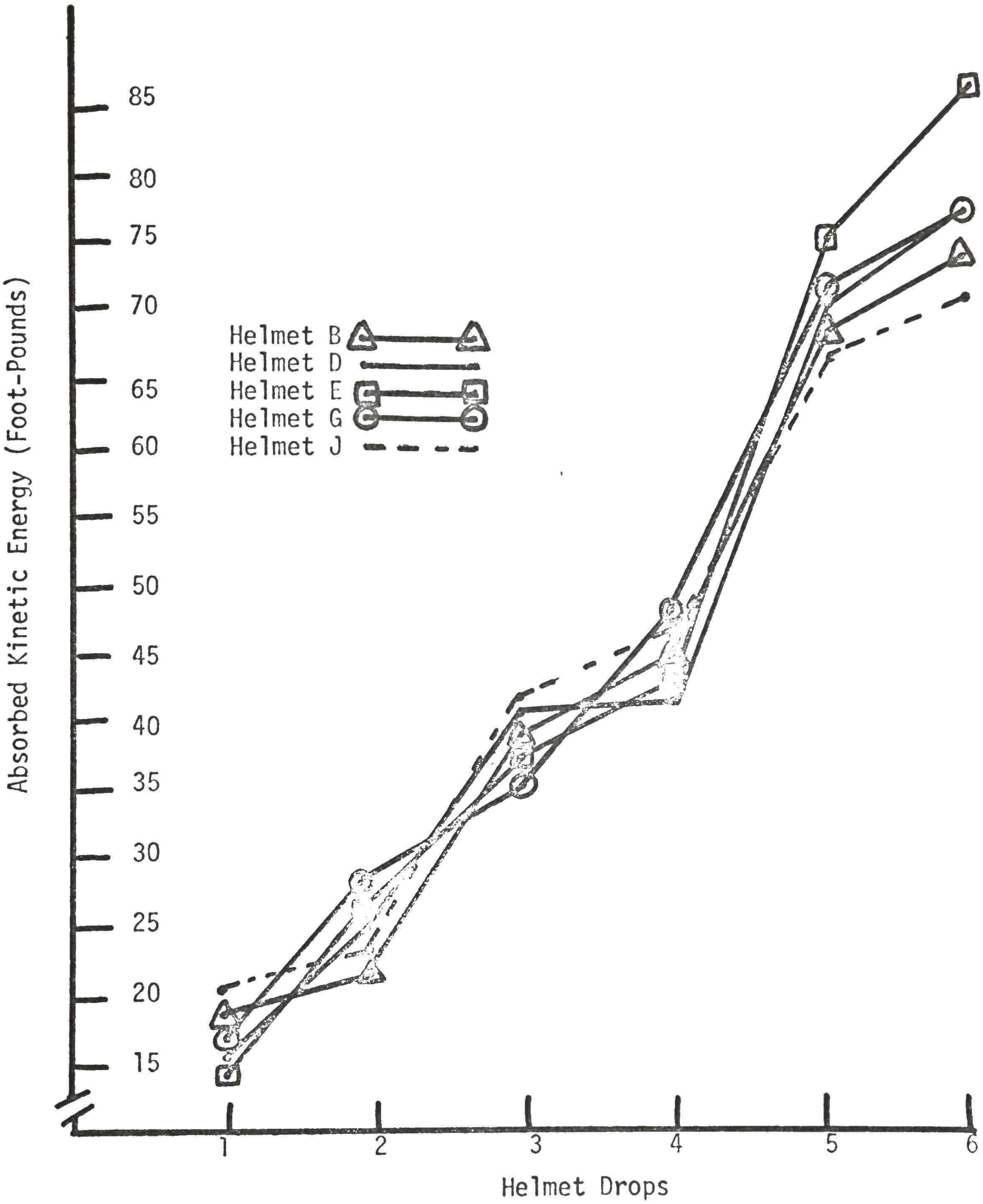

Fig. 4.--Absorbed energy for youth model helmets

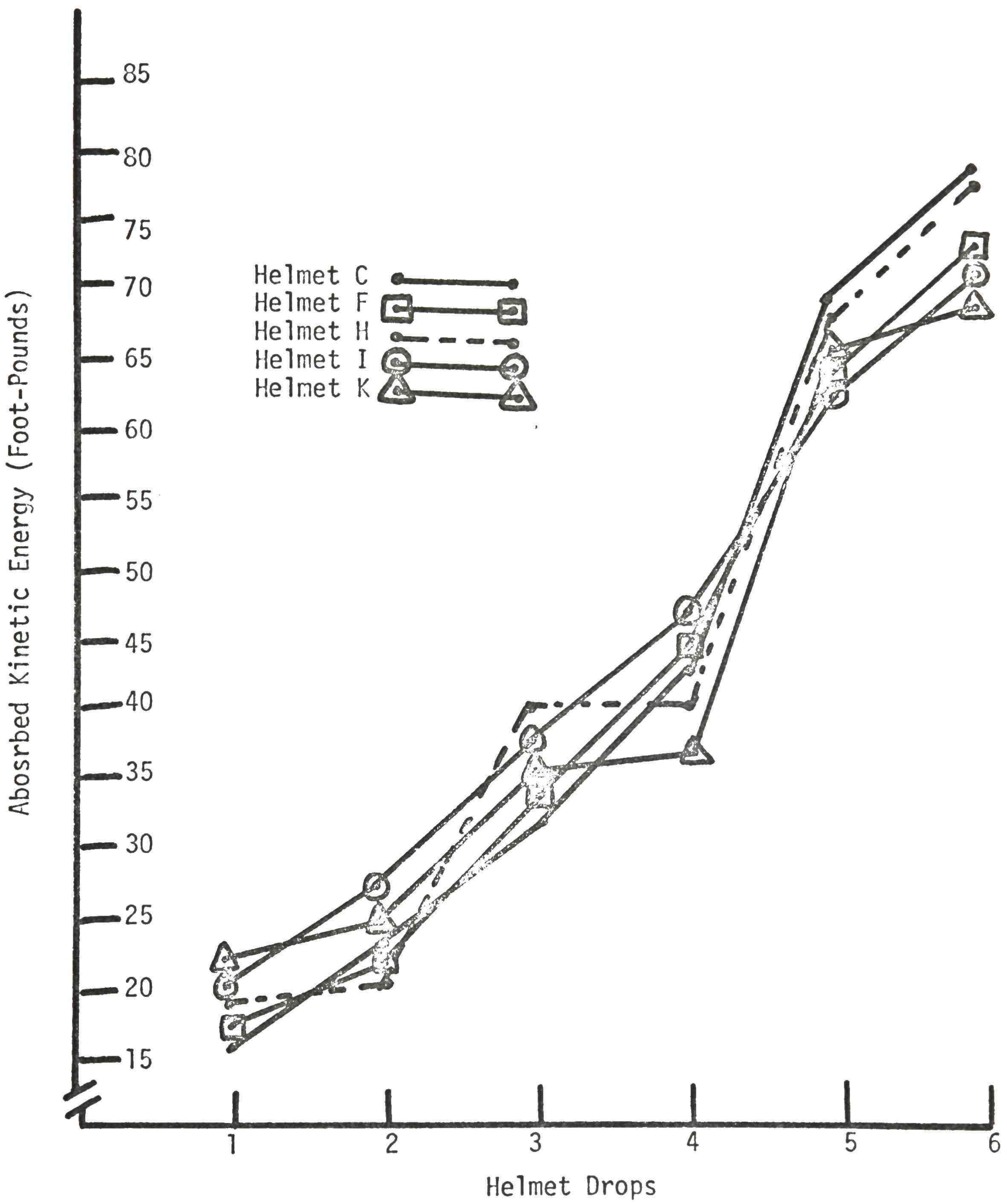

Fig. 5.--Absorbed energy for professional model helmets

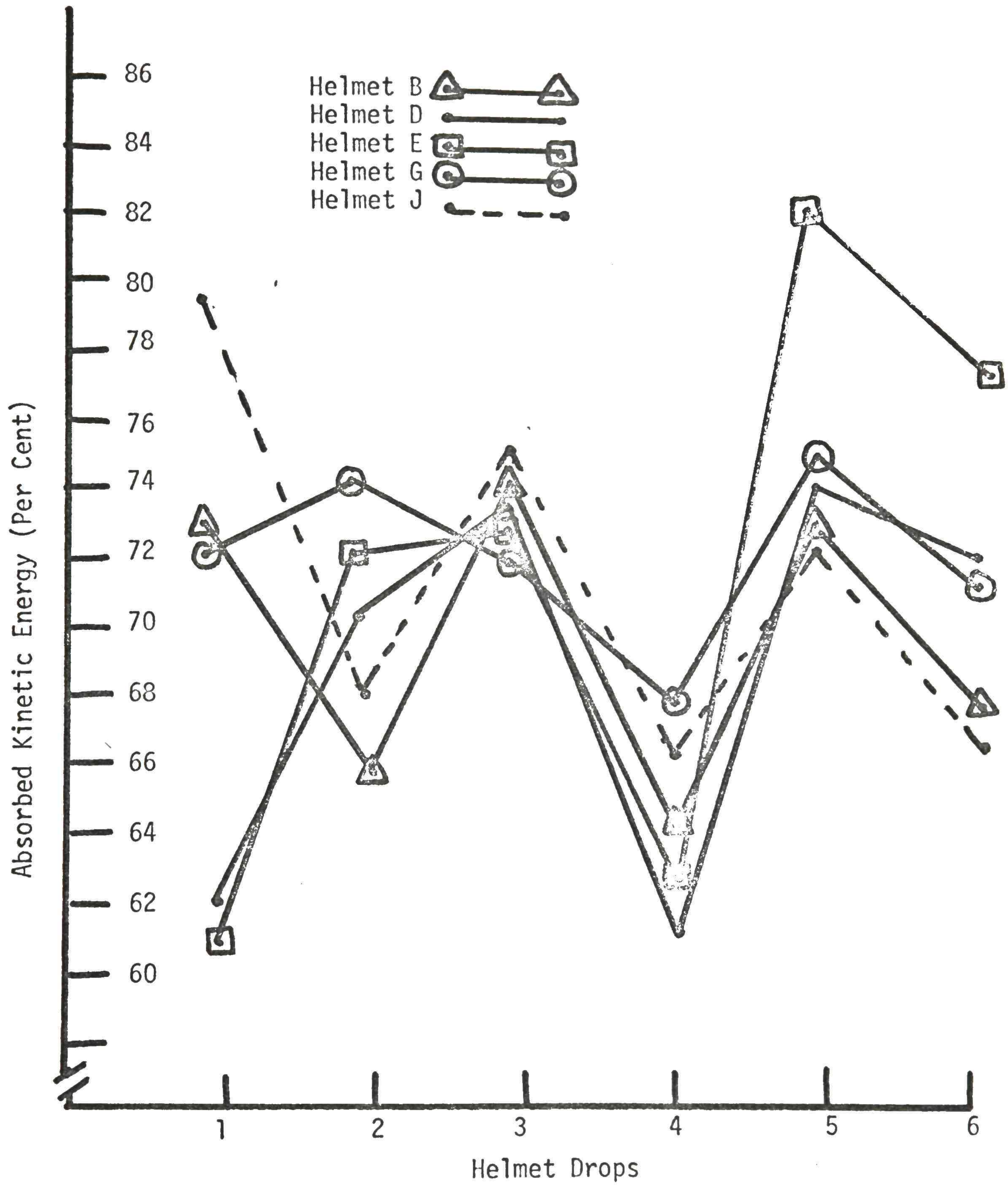

Fig. 6.--Absorbed energy for youth model helmets

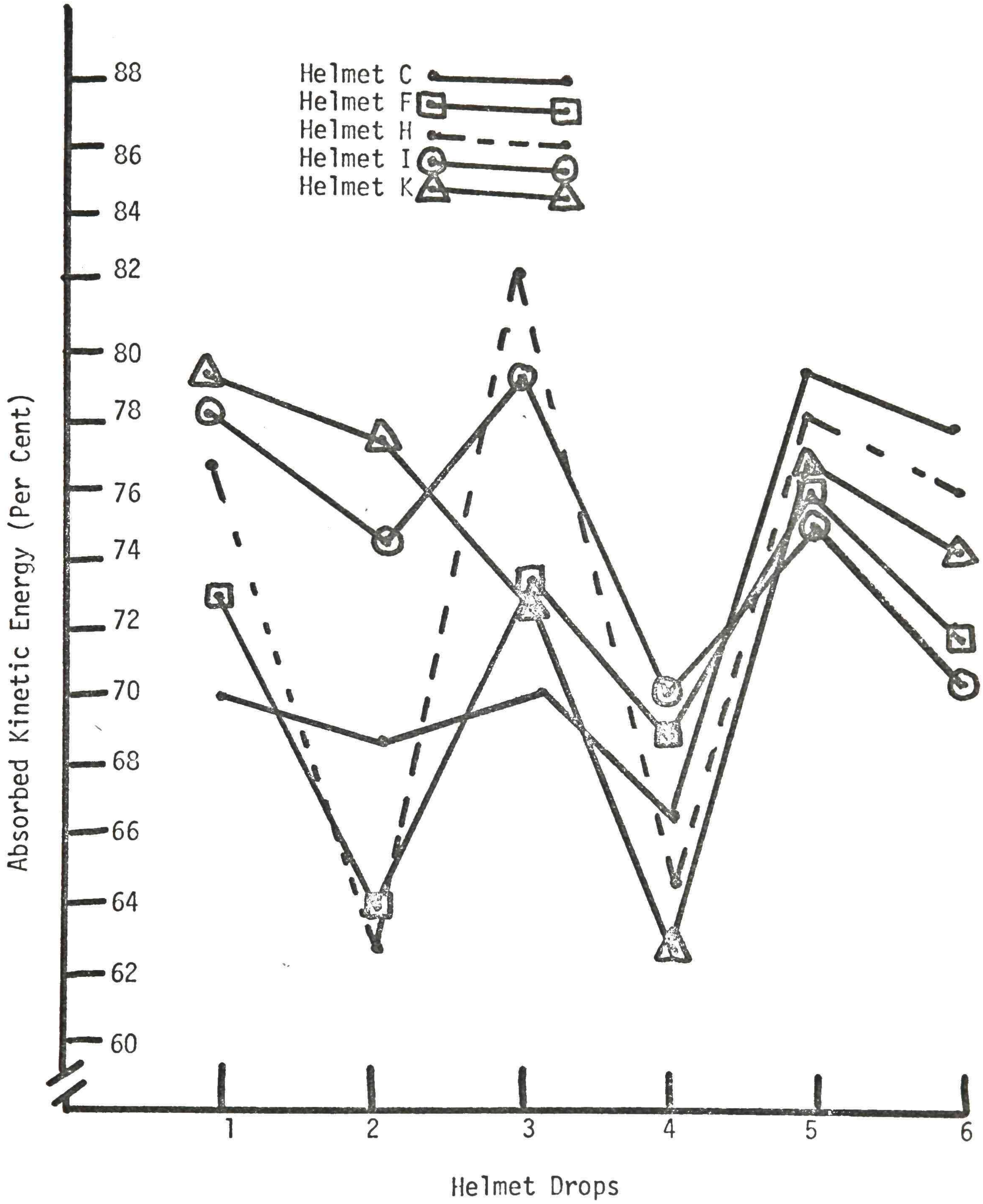

Fig. 7.--Absorbed energy for professional model helmets

varied in their ability to absorb K.E. at each drop height.

Table 5 contains a summary of the acceptability of the helmets when compared to the American National Standards Institute (1) specifications for protective headgear. None of the helmets exceeded a peak acceleration of 400 G's. However, helmets B, C, D, E, F, G, J, and K were unacceptable because they had a peak acceleration of over 200 G's with a duration over 2 milliseconds. Helmet H was the only one that

TABLE 5

SUMMARY OF THE ACCEPTABILITY OF THE HELMETS

Helmet	Peak Acceleration in G's	Acceptable or Unacceptable	Height of Failure	Trial of Failure
B	299.48	Unacceptable	6	1
C	319.01	Unacceptable	6	1
D	329.86	Unacceptable	6	1
E	329.86	Unacceptable	6	7
F	366.75	Unacceptable	6	1
G	334.20	Unacceptable	6	9
H	273.44	Acceptable*	--	--
I	91.61**	Unacceptable	1	1
J	334.20	Unacceptable	6	1
K	319.01	Unacceptable	6	1

* Was acceptable for the twenty additional trials of the study.
** Cracked on Trial 1.

did not exceed the acceptable peak acceleration level. Helmet I was unacceptable because it cracked on the first drop height. Helmets B, C, D, F, J, and K all exceeded the peak acceleration level after the initial trial. At the sixth drop height, Helmets E and G did not exceed the acceptable peak acceleration level until they were given additional trials at the sixth drop height. Helmet E reached an unacceptable peak acceleration level after six additional trials. Helmet G failed after eight additional trials.

A chi square analysis with the Yates Correction for Continuity (6) technique was used to examine the relationship between the price range of the helmets, model of the helmets, and acceptability of the helmets. Table 6 gives a summary of the chi square analysis. The findings indicate that at .05 level of confidence no significant relationship existed between: (1) the price range of the helmets and the model of the helmets, (2) the price range of the helmets and the acceptability of the helmets, and (3) the model of the helmets and the acceptability of the helmets.

TABLE 6

SUMMARY OF CHI SQUARE ANALYSIS

Row Variables	Column Variables	X^2	Probability
Model	Price	0.416	$< .05$
Price	Acceptability	0.047	$< .05$
Model	Acceptability	0.000	$< .05$

A point biserial correlation was used to determine the relationship between absorbed energy for each helmet and the acceptability of each helmet at the initial trial of the sixth drop height. Table 7 contains a summary of the absorbed energy and acceptability of the helmets. The correlation of .21 was found not significant at the .05 level of confidence.

TABLE 7

HELMET ABSORBED KINETIC ENERGY AND ACCEPTABILITY FOR INITIAL TRIAL

Helmet	Absorbed Kinetic Energy	Acceptability
B	74.19	Unacceptable
C	81.79	Unacceptable
D	76.33	Unacceptable
E	84.04	Acceptable
F	75.13	Unacceptable
G	76.32	Acceptable
H	80.18	Acceptable
I	74.16	Unacceptable
J	70.62	Unacceptable
K	76.84	Unacceptable

Summary of Findings

The findings of the study were:

(1) There was not a significant difference between youth model and professional model helmets and the resulting peak acceleration.

(2) Peak acceleration increases significantly for both youth and professional model helmets with increases in velocity.

(3) All helmets tested demonstrated variability in absorbing the same percentage of impact K.E. at each drop height.

(4) Nine of the ten helmets tested passed all of the standards for acceptability at the first five K.E.'s. However, only one helmet had an acceptable peak acceleration level at the sixth K.E. level after 20 additional trials at that level.

(5) There was no significant relationship between: (a) the price range of the helmets and the model of the helmets, (b) the price range of the helmets and the acceptability of the helmets, and (c) the model of the helmets and the acceptability of the helmets.

(6) There was a low positive correlation between acceptability of the helmets and the absorbed K.E. at the initial trial of the sixth drop height.

Discussion of Findings

The findings of the study support the hypothesis that there are differences in the protection provided by baseball batting helmets. Only helmet H of the 10 helmets tested passed all of the standards for all K.E. levels and all trials. Although nine of the 10 helmets were acceptable at the first five K.E. levels, it is possible that a player may be struck by a pitched ball with a K.E. greater than at which these helmets were determined acceptable.

The study found that there was no significant difference between models in peak acceleration. Since acceptability standards were based on peak acceleration, it may be concluded that there was no difference in the protection provided by youth and professional model helmets.

The study found that price range had no effect upon the protection provided by the helmet model. This fails to support the contention of Fagan (4) and Robey (14) that low priced protective equipment does not provide the protection of higher priced protective equipment.

The findings of the study support the hypothesis that the design and materials used in making the helmet are determining factors in the protection helmets provide. The helmets were of two basic designs: (1) with ear flaps, and (2) without ear flaps. The shells of the helmets were made of either: (1) cycolac, (2) herculac, (3) fiberglass, or (4) lexan. The material lining the shell of the helmets was either: (1) foam vinyl or (2) closed cell vinyl. Helmet H, which was the only helmet to pass all of the standards for all K.E. levels and all trials, had two ear flaps, a lexan shell, and closed cell vinyl lining. This was the only helmet tested that had this combination of design and materials. Helmet I, which was unacceptable because it cracked on the first drop height, had the same shell and lining materials as helmet H but it was designed without ear flaps. Helmet F, which began to splinter early in testing, was the only helmet tested with a fiberglass shell, foam vinyl lining, and it too was designed without ear flaps. Helmet G had the same design and shell material as helmet H but the lining material was different. Helmets B, C, D, E, J, and K had the same design as helmet H but both their shell and lining materials were different.

None of the helmets tested had a suspension type helmet mounting. Football helmets with this type of mounting system have been shown to have a significantly lower concussive injury rate.

Summary

A description of the data, the analysis of data, the findings derived from the data, and a discussion of these findings were presented in this chapter.

CHAPTER V

SUMMARY

Statement of Purpose

The purpose of this study was: (1) to determine if a baseball batting helmet can endure the impact of a pitched baseball at velocities of 50, 60, 70, 80, 90, and 100 miles per hour, (2) to determine how much of this impact is transmitted to the head, and (3) to compare different models of helmets for their qualitites of impact and transmission of impact.

Procedure

The study tested five youth model and five professional model batting helmets on an aluminum headform. An Endevco accelerometer was built into the headform which gave a readout on the amount of K.E. transmitted to the headform. This readout was analyzed by a Digital PDP-12 computer which gave: (1) the peak acceleration, (2) total velocity change, (3) absorbed energy, (4) impact velocity, and (5) rebound velocity. The helmets were dropped at six heights to create the K.E. of baseball being thrown at 50, 60, 70, 80, 90, and 100 miles per hour. All helmets were given one trial at each height. Those helmets which had not failed after the initial trial were tested further until they failed or until they received twenty additional trials at the sixth drop height.

Summary of Findings

The findings of the study were:

(1) There was not a significant difference between youth model and professional model helmets and the resulting peak acceleration.

(2) Peak acceleration increases significantly for both youth and professional model helmets with increases in velocity.

(3) All helmets tested demonstrated variability in absorbing the same percentage of impact K.E. at each drop height.

(4) Nine of the 10 helmets tested passed all of the standards for acceptability at the first five K.E.'s. However, only one helmet had an acceptable peak acceleration level at the sixth K.E. level after twenty additional trials at that level.

(5) There was no significant relationship between: (a) the price range of the helmets and the model of the helmets, (b) the price range of the helmets and the acceptability of the helmets, and (c) the model of helmets and the acceptability of the helmets.

(6) There was a low positive correlation between acceptability of the helmets and the absorbed K.E. energy at the initial trial of the sixth drop height.

Conclusions

The findings of this study support the following conclusions:

(1) Nine of the ten helmets tested could not provide sufficient protection to meet the K.E. demands of a baseball thrown at 100 miles per hour but could meet these K.E. demands at lower velocities.

(2) One helmet showed that its design and the materials used in manufacturing it were superior to the other helmets tested.

(3) At the present time the selected safety factors provided by baseball batting helmets must be questioned.

Recommendations

The following recommendations are made for further study of baseball batting helmets:

(1) Another study should be conducted to establish a standard of acceptable peak acceleration for baseball batting helmets.

(2) Another study should be conducted in which the baseball is projected against a batting helmet mounted on a stationary headform.

(3) Another study should be conducted to determine the reason or reasons for the low positive correlation between absorbed energy and the acceptability of the helmets.

(4) Develop a batting helmet with a suspension-type helmet mounting, and test it for the selected safety factors used in this study.

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APPENDICES

APPENDIX A

RAW DATA: PEAK ACCELERATION IN G'S FOR INITIAL TRIALS

Helmet Code	Helmet Drop					
	1	2	3	4	5	6
B	110.68	149.74	206.16	234.37	241.74	299.48
C	108.51	188.80	232.21	269.09	258.25	319.01
D	138.89	169.27	173.61	260.42	277.77	329.86
E	123.70	169.27	199.65	227.00	278.00	268.46
F	117.19	138.89	184.46	225.69	260.42	366.75
G	115.02	125.87	190.98	225.69	308.16	317.46
H	117.19	117.19	151.91	177.95	219.18	256.07
I	91.61	104.17	133.00	201.82	260.42	256.07
J	95.48	156.25	164.93	234.37	247.39	334.20
K	123.69	151.91	164.93	273.44	295.14	319.01

APPENDIX B

RAW DATA: ABSORBED ENERGY IN FOOT-POUNDS FOR INITIAL TRIALS

Helmet Code	Helmet Drop					
	1	2	3	4	5	6
B	19.36	25.56	39.08	44.79	65.89	74.19
C	18.24	25.97	35.96	44.76	69.32	81.79
D	16.57	27.62	38.98	42.47	66.27	76.33
E	16.462	28.12	38.78	43.73	74.21	84.04
F	19.02	24.59	37.62	45.21	66.79	75.13
G	19.29	28.79	38.45	46.08	67.07	76.32
H	19.82	24.00	42.35	42.95	68.38	80.18
I	20.28	28.08	40.46	46.00	66.25	74.16
J	21.09	26.66	39.57	45.37	65.71	70.62
K	20.46	27.49	37.77	41.28	67.51	73.47

APPENDIX C

SUMMARY OF HELMETS USED IN THE STUDY

Helmet	Model	Price	Lining Material	Shell Material	Design
B	Youth	$ 9.75	Foam Vinyl	Cycolac	Ear Flaps
C	Pro	$ 8.95	Foam Vinyl	Herculac	Ear Flaps
D	Youth	$ 6.95	Foam Vinyl	Herculac	Ear Flaps
E	Youth	$ 9.50	Foam Vinyl	Cycolac	Ear Flaps
F	Pro	$11.50	Foam Vinyl	Fiberglass	Without Ear Flaps
G	Youth	$10.40	Foam Vinyl	Lexan	Ear Flaps
H	Pro	$13.00	Closed Cell Vinyl	Lexan	Ear Flaps
I	Pro	$12.40	Closed Cell Vinyl	Lexan	Without Ear Flaps
J	Youth	$ 7.95	Foam Vinyl	Cycolac	Ear Flaps
K	Pro	$ 7.95	Foam Vinyl	Cycolac	Ear Flaps