

Dangerous Decision



Photo Courtesy of Boeri USA, Inc.

The Consideration For Helmet Use At Any Speed

by
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Abstract

This project was designed to determine if, in a simple topple scenario, a cyclist's bare head would fall far enough to create sufficient velocity, energy, and force to cause a significant head and/or brain injury colliding with the ground.

A standard fall-height model was defined for three age ranges using common bike-fit standards and data from an anthropometrical survey. Then a device to simulate the start height and fall path of the human head was constructed and a Photogate Timer used to accurately measure the velocity of the simulated head upon impact with the ground.

A correlation was established between impact velocities, skull fractures, concussive events, helmet standards, and g-forces of a bare head colliding with various theoretical surfaces. The results showed two to five times the g-forces necessary for a serious head injury. The impact energies were then compared against a current helmet standard and showed that a helmet meeting that standard would have most likely protected the "victim."

My test results and research convincingly suggest that the velocity and energy created in a simple tip-over fall, onto a hard surface, are more than great enough to cause a serious head and/or brain injury to a cyclist not wearing a helmet, regardless of ground speed.

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* All Photo credits within this project go to researcher and adult supervisor unless otherwise indicated

I. Introduction

Would you voluntarily run at a full sprint headfirst into a brick wall? Now, think of sitting on a bicycle without a helmet, and then tip over with a little over a second to intervene before your bare head hits the ground. Which sounds worse?

Despite the fact that bicycle helmets are considered the single best means of protecting cyclists from the leading causes of head injuries and death, many people still choose not to wear them stating that:

“I don’t ride fast enough to need a helmet.”

That is the choice many riders make to become one of the 67,000 cyclists who will suffer a head injury this year.

From the height of a recreational riding position, a simple tip-over fall can create enough speed and energy to cause substantial damage to the human head and brain. In other words, it is the height of the potential fall and not just the speed the cyclist is traveling where the threat of injury exists.

The foundation of this project involves three primary steps:

- 1) Define a Fall Height Model using a combination of existing anthropometrical data and generally accepted bike-fitting standards for three different age groups.
- 2) Construct a device to simulate a simple fall (topple) scenario of the human head at the determined heights.
- 3) Conduct testing to measure velocity of the simulated head upon impact with the ground using a highly accurate Photogate Timer.

The goal is to calculate the forces and energies encountered by the human head and brain in this type of fall scenario, and then compare with known helmet standards and brain injury thresholds.

II. Question

Problem

Should a helmet be used for head protection while riding a bicycle regardless of ground speed?

Purpose

This project will determine the velocity at which the human head is traveling and subsequent energies and forces it experiences when colliding with the ground from common ride heights in a basic topple scenario.

Hypothesis

From an average upright riding position, a cyclist's head will fall far enough to create sufficient velocity, force, and energy to cause a significant head and/or brain injury.

III. Anthropometrical Model

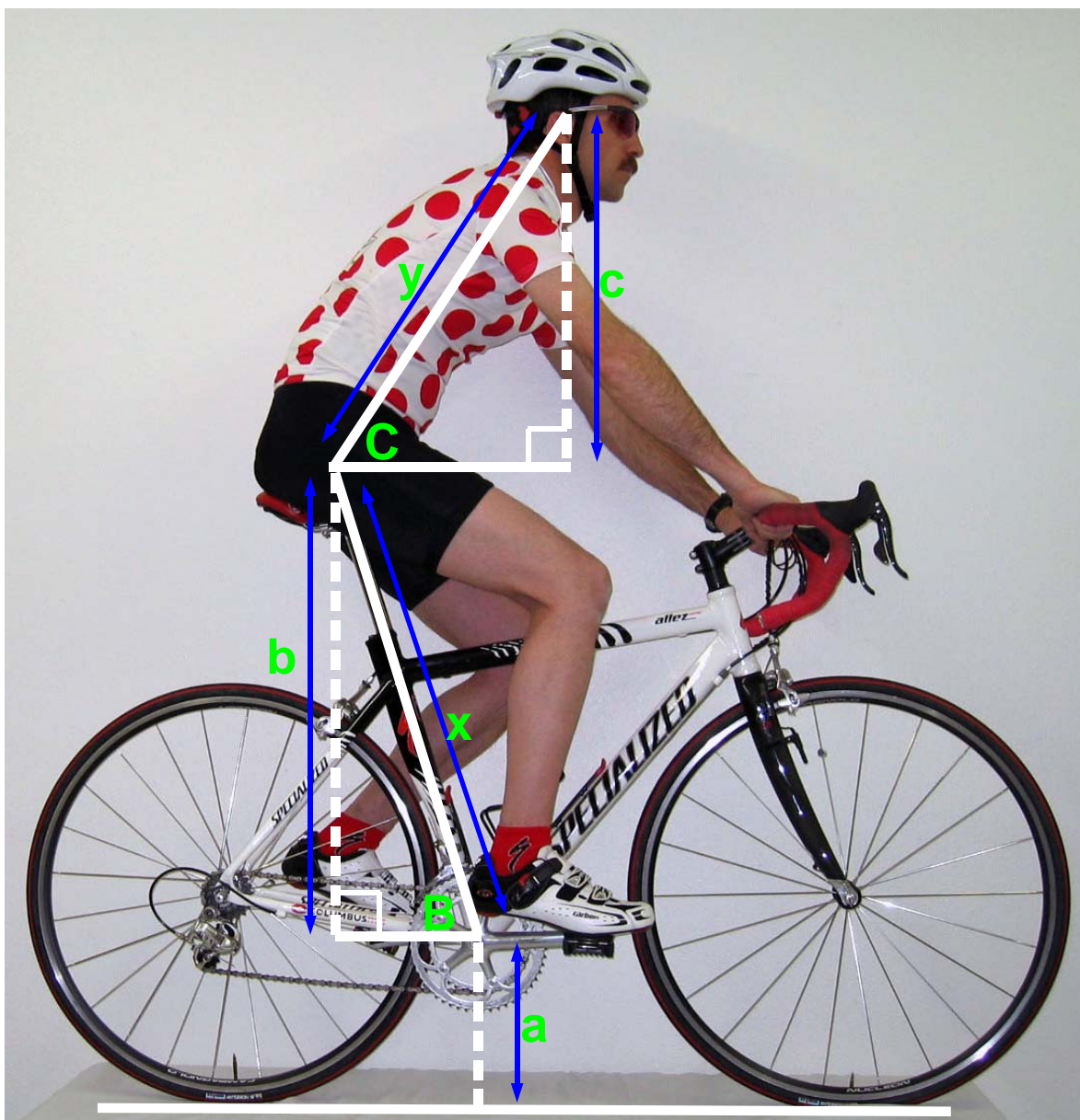
Before construction of a Head Fall Simulator (HFS), a standard test fall-height model had to be established for three age ranges. Using common bike-fit standards and results from a survey sponsored by the Consumer Products Safety Commission in 1975, the average head height of riders were determined for the age ranges defined for this project. Over 1,000 test subjects participated in the CPSC survey from ages 2 to 19.

After consultation, it was determined that age 19 would represent the adult height model because on average most adults quit gaining height between the ages of 16 and 19. The age ranges used, correlated back to the three most common-sized bicycles ridden by the general population; 12, 24, and 26 inch (wheel size) bikes.

The method used is as follows: (refer to illustration on following page)

- Measure bottom bracket (BB) height (a) from sample bikes
- Measure seat tube angle (B) from sample bikes
- Using anthropometrical Trochanteric Height data, compute seat height (x), using common factor (Lemond Method).
- Solve right-triangle problem to calculate BB to seat height (b)
- Using anthropometrical Eye Height (y) and rider-back angle (C), solve right-triangle problem to calculate seat-to-head height (c)
- Add BB height (a) to BB/seat height (b) to seat/head height (c) to determine head-fall heights for test age groups

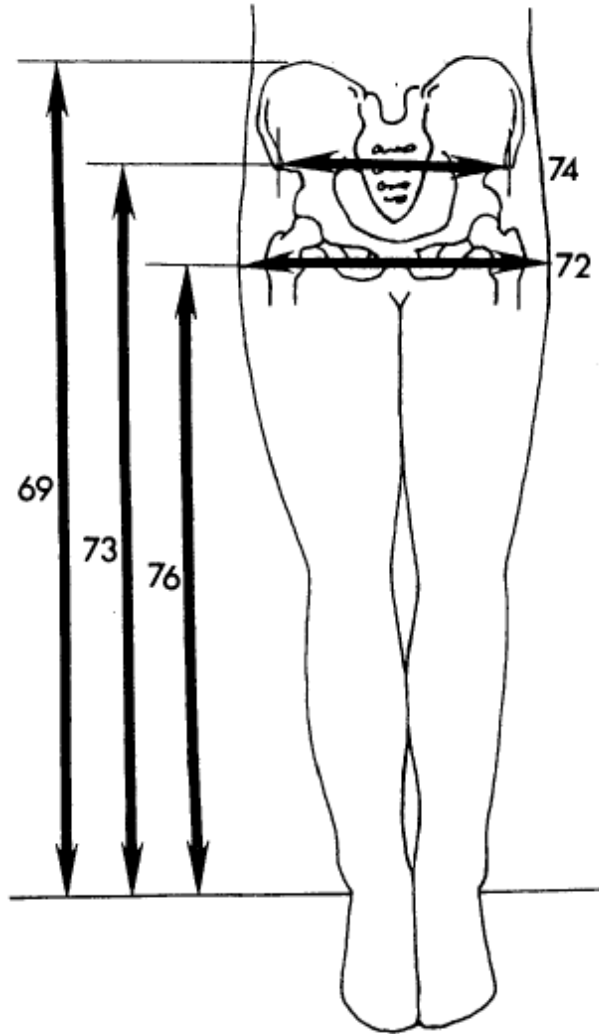
III.a. Head-Fall Height from Anthropometrical Data



ALL DIMENSIONS IN CENTIMETERS

Age Group			6.5 (h1)	12.5 (h2)	19 (h3)
Bottom Bracket (BB) Height		(a)	23	27	31.5
Trochanteric Height	(Inseam)		58.3	79	86.7
Seat Height Factor	(Lemond Method)		0.883	0.883	0.883
Seat Height	(Inseam * factor)	side (x)	51.48	69.76	76.56
Seat Tube Angle		angle (B)	69	73	73
		sin (B)	0.934	0.956	0.956
BB to Seat Height	$b = \sin(B) * x$	side (b)	48.06	66.71	73.21
Eye Height (Sitting)		side (y)	53.15	66.55	77.90
Rider Back Angle	(recreational)	angle (C)	45	45	45
		sin (C)	0.707	0.707	0.707
Seat-to-Head Height	$c = \sin(C) * y$	side (c)	37.58	47.06	55.08
Total Head-Fall Height	$a + b + c$	cm	108.64	140.77	159.79

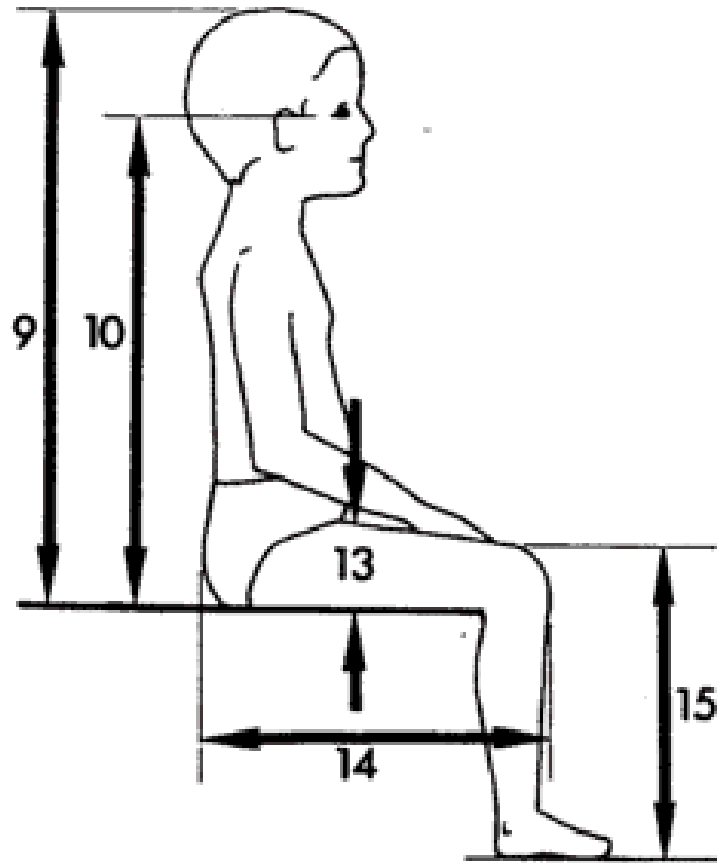
III.b. Anthropometrical Trochanteric Height - Dimension (76)



TROCHANTERIC HEIGHT (in cm) - MALES AND FEMALES								
AGE/YRS	N	MEAN	S.D.	MIN	5TH	50TH	95TH	MAX
2.0-3.5	67	42.6	3.3	35.0	37.0	42.6	48.3	49.3
3.5-4.5	79	46.9	3.4	41.2	42.0	46.5	52.3	58.7
4.5-5.5	76	51.6	3.0	45.4	46.3	51.7	55.9	58.7
5.5-6.5	77	56.3	3.3	50.2	51.2	55.8	62.1	68.5
6.5-7.5	73	60.3	3.7	52.7	54.8	59.8	66.3	69.9
7.5-8.5	64	63.6	3.5	54.5	57.0	63.9	68.9	70.7
8.5-9.5	80	67.5	3.8	60.4	61.0	67.6	73.1	76.4
9.5-10.5	75	71.3	4.4	64.1	64.6	70.8	79.8	82.3
10.5-11.5	97	74.2	4.7	64.4	66.0	74.2	81.3	86.1
11.5-12.5	96	77.3	4.8	67.4	70.0	76.6	84.7	92.3
12.5-13.5	100	80.7	4.9	68.2	72.6	80.5	88.9	96.4
13.5-14.5	82	82.8	5.3	65.8	73.8	82.6	91.0	93.8
14.5-15.5	87	84.2	5.0	72.0	74.8	84.6	90.8	94.2
15.5-16.5	63	85.9	6.2	74.2	76.8	86.2	95.3	99.6
16.5-17.5	74	85.8	6.0	72.4	75.8	84.8	95.2	100.9
17.5-19.0	46	86.7	6.6	75.9	76.5	86.7	98.1	100.7

Illustration and chart courtesy of the National Institute of Standards and Technology

III.c. Anthropometrical Eye Height, Seated - Dimension (10)



EYE HEIGHT, SITTING (in cm) - MALES AND FEMALES								
AGE/YRS	N	MEAN	S.D.	MIN	5TH	50TH	95TH	MAX
2.0-3.5	64	43.7	2.5	38.2	39.0	43.5	47.5	50.0
3.5-4.5	75	46.8	2.8	38.5	41.9	46.6	51.6	52.9
4.5-5.5	90	49.8	2.8	41.5	45.2	49.7	54.5	56.9
5.5-6.5	79	51.9	2.9	43.2	46.6	52.2	56.6	60.2
6.5-7.5	87	54.4	2.8	47.3	49.8	54.1	59.3	62.3
7.5-8.5	67	57.1	2.9	51.5	52.0	57.1	62.0	63.3
8.5-9.5	90	59.4	3.2	49.1	53.7	59.3	64.7	66.9
9.5-10.5	84	60.5	3.0	54.3	55.2	60.6	64.8	67.3
10.5-11.5	85	62.5	3.5	54.6	57.1	62.4	69.2	73.2
11.5-12.5	97	65.0	3.2	58.7	60.1	64.8	69.9	76.7
12.5-13.5	107	68.1	4.2	60.4	61.2	68.0	75.1	79.9
13.5-14.5	89	71.1	4.1	59.0	64.0	71.6	77.6	80.4
14.5-15.5	81	73.9	4.3	62.8	66.8	73.6	80.5	83.4
15.5-16.5	77	76.0	4.4	61.0	69.2	75.9	83.3	85.8
16.5-17.5	66	76.9	4.2	67.5	69.9	77.3	83.0	85.4
17.5-19.0	63	77.9	4.3	67.8	70.0	78.7	83.4	85.5

Illustration and chart courtesy of the National Institute of Standards and Technology

IV. Head-Fall Simulator

A device to simulate the height and path of the human head in a simple topple scenario had to be constructed, since use of human subject was obviously not an option. The device's only similarity to an actual human is the height of the head, since it was out of my ability to model a real human. Fortunately, Galileo and Newton learned that all falling objects accelerate at the same rate due to gravity. Therefore, the Head-Fall Simulator (HFS) will deliver a good approximation for this experiment.

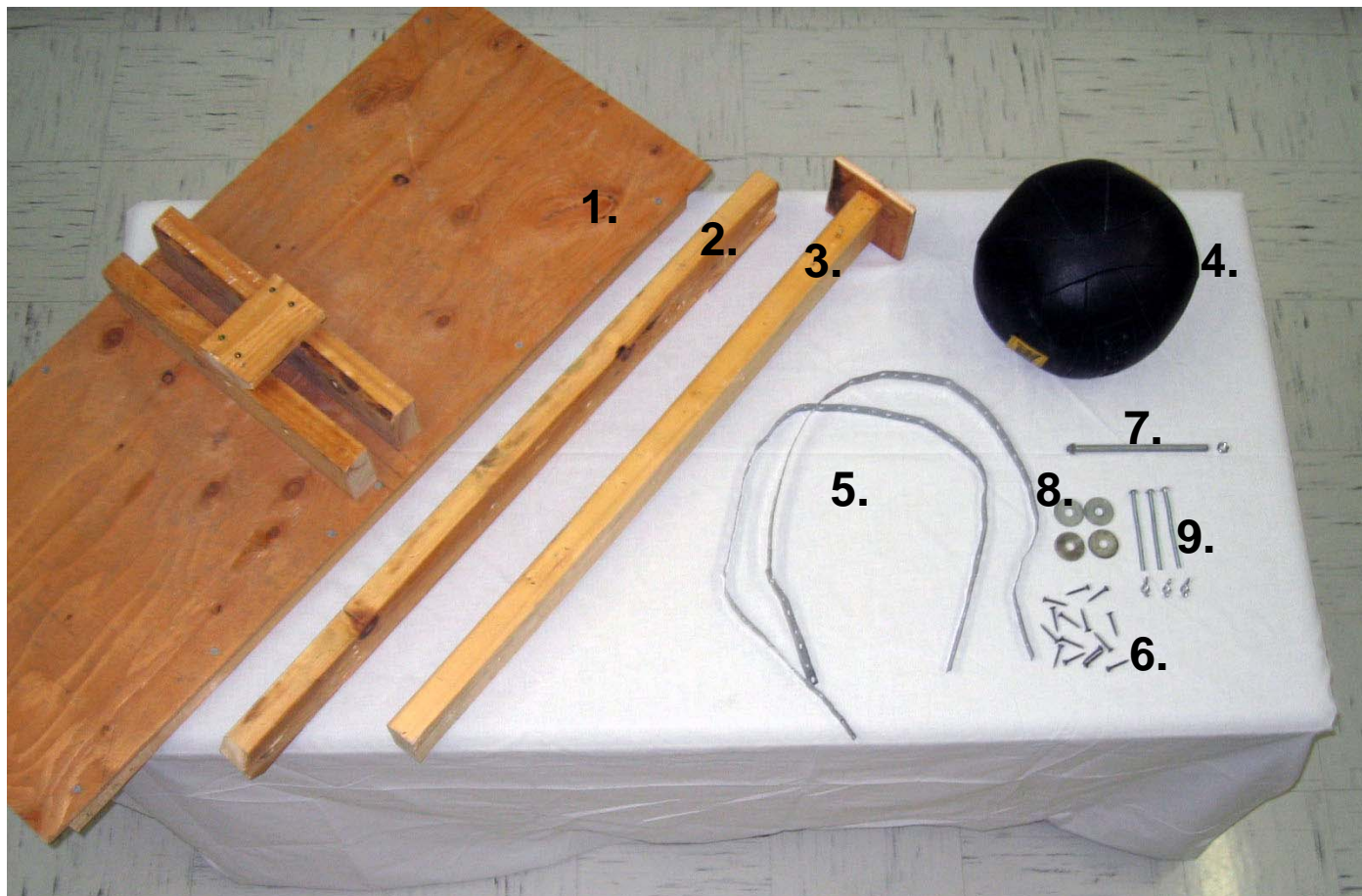
This device had to be: stable to produce consistent fall times measured by the Photogate Timer, durable to survive repeated impacts, extendable to represent all the head heights tested, and portable. Lastly, a stop was integrated into the design to present a consistent five-degree off-center starting point. So, using 2x4s, a medicine ball, plywood, and various fasteners, a contraption was constructed that met the criteria.

To measure the velocity of the HFS head at impact, a Photogate Timer was used to measure the timing of the leading edge and trailing edge of a tab passing through a light beam. A recipe card functioning as a tab was attached to the upper leg of the HFS arm. The Photogate Timer was placed on the ground so that the tab would finish cutting the light beam slightly before the HFS head collides with the ground.

Knowing the size of the tab enables us to calculate the velocity, using the equation $v = d/t$, where v is equal to velocity, d is equal to the width of the tab, and t is the time it took for that tab to fully pass through the light beam.

By using the ratio between the tab's position and the head's position on the HFS, the head velocity at collision could be calculated.

IV.a. Head-Fall Simulator - Parts List



	Name	Material	Dimension	Quantity
1.	Base	3/8" AC Plywood	117x47 cm	1
2.	Lower Leg	2x4 with pivot hole	90.2 cm	1
3.	Upper Leg	2x4 with ball support	90.2 cm	1
4.	Medicine Ball	Everlast Brand Medicine Ball	2.845 kg	1
5.	Ball Straps	Plumbers Tape	200 cm	2
6.	Strap Screws	Sheet Rock	1.5"	15
7.	Pivot Axis	All-Thread Bolt	3/8" x 18 cm	1
8.	Pivot Washers	Fender Washers	3/8"	4
9.	Leg Bolts	1/4" Treaded w/Wing Nuts	8.89 cm	3

IV.b. Head Fall Simulator — Complete



IV.c. Pasco Model ME-9403 Photogate Timer



Photo Courtesy of Pasco, Inc.

V. Procedure

1. Assemble Head-Fall Simulator (HFS) at test site
2. Stack lead bricks on HFS base to keep stable
3. Using tape, attach tab to HFS arm in safe zone near base of ball
4. Set the length of HFS arm to the first head-height test position with ball on ground
 - 4.1 Position Photogate Timer (PGT) on ground where fall path of tab cuts beam and top of tab finishes passing through beam slightly before ball impacts ground
 - 4.2 Position more lead bricks to protect PGT from an unexpected fall path of HFS arm
 - a. Pull arm back to start position against stop
 - b. Have assistant reset PGT to zero
 - c. Gently release HFS arm
 - d. Record time reading on PGT
 - e. Repeat steps a - d seven times
 - f. Record distance from center of hinge to tab location
5. Repeat routine 4 with remaining head-height test positions
6. Calculate the velocity of the fall of the arm at tab position
7. Using ratio, calculate simulated head velocity at impact
 - Of secondary interest was the total duration of the fall, to determine rider reaction time. Before resetting the HFS to a new height, a second Photogate was positioned to be triggered at the top of the fall. The timer would keep going until the gate at the bottom was triggered, displaying total time of the fall. This procedure was repeated three times, and the results were averaged.

VI. Data and Calculations

Measured Tab Photogate Times - milliseconds		Age 6.5	Age 12.5	Age 19
Fall	Height 1 (h1)	Height 2 (h2)	Height 3 (h3)	
	1	0.022	0.017	0.016
	2	0.022	0.018	0.016
	3	0.022	0.017	0.016
	4	0.022	0.017	0.016
	5	0.022	0.017	0.016
	6	0.022	0.017	0.016
	7	0.022	0.017	0.016
Average Tab Photogate Time	msec	0.022	0.017	0.016

Tab Velocity - meters/second				
Tab Size	m	0.07626	0.07626	0.07626
Tab Velocity	m/s	3.47	4.45	4.77

Correction for Simulated Head Velocity - meters/second				
Tab Location on HFS Leg	cm	79.0	111.2	129.7
Head Location on HFS Leg	cm	108.64	140.77	159.79
Simulated Head Velocity	m/s	4.77	5.63	5.87
	mph	10.63	12.56	13.10

Theoretical Head Velocity at Impact by Dr. Emmons's Formula - meters/second				
Theoretical Head Velocity	m/s	5.09	6.02	6.49
	mph	11.35	13.43	14.48
Difference Between Measured and Theoretical		+ 6.3%	+ 6.5%	+ 9.5%

Total Fall Time - seconds - (reaction time to prevent fall)				
	1	1.184	1.367	1.377
	2	1.198	1.397	1.400
	3	1.204	1.321	1.391
		1.195	1.362	1.389

Equivalent Straight Drop Height - (fall-out-of-bed scenario)				
Tested Topple Height	m	1.09	1.41	1.60
	ft	3.6	4.6	5.2
Equivalent Drop Height	m	1.16	1.62	1.76
	ft	3.8	5.3	5.8

Energy at Impact				
Total "victim" weight	kg	22.1	43	65.7
Head weight at 8.23% of total	kg	1.82	3.54	5.41
	joule	20.67	56.11	93.22

VII. Results

The Head-Fall Simulator (HFS) performed well, producing very consistent drop times and velocities. As expected, when the fall heights increased, the total time it took for the tab to pass through the Photogate decreased, meaning that the arm was traveling faster upon impact (see chart “Tab-Fall Time and Simulated Head Velocity”).

		h1 (6.5 yr) 108.64cm	h2 (12.5 yr) 140.77cm	h3 (19 yr) 159.79cm
Average Tab Time	msec	.022	.017	.016

After determining the tab velocities, the simulated head velocities at impact were calculated using the ratio between the tab’s position and the head’s position on the HFS.

		h1	h2	h3
Simulated Head Velocity	m/s	4.77	5.63	5.87
	mph	10.63	12.56	13.10

To verify the test results, a professor of physics assisted in the use of a mathematical formula to calculate the theoretical velocity of the HFS. There was an approximate 6% to 10% increase from the directly measured to the hypothetical results. The assumed reason for these differences is the slowing effect of air resistance and pivot friction.

		h1	h2	H3
Theoretical Head Velocity	m/s	5.09	6.02	6.49
	mph	11.35	13.43	14.48
Difference		+ 6.3%	+ 6.5%	+ 9.5%

A correlation needed to be established between impact velocity and accelerations, since head-impact research is based on potential of injury at various g-forces (g’s). Wayne State University researchers determined that the human skull fractures and concussive events occur at accelerations associated around an average range of 112 g’s to a peak of 200 g’s for this type of event.

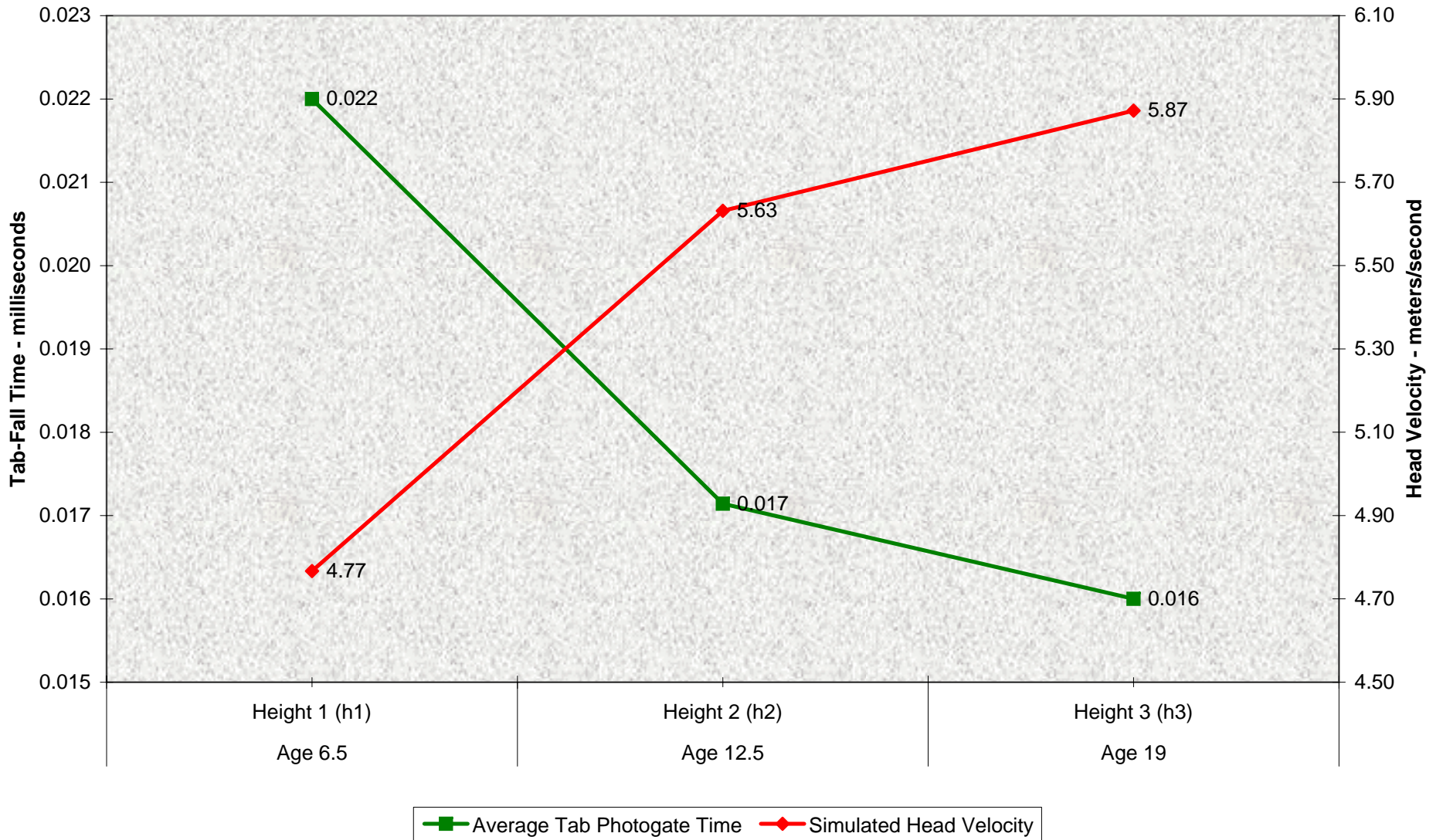
To determine g-forces, we have to estimate the time it takes the head to go from the velocity it is traveling at impact to zero. The whole head does not stop in an instant when colliding with a surface; it takes milliseconds for the rest of the head to experience the velocity change. Snell Memorial

Foundation researchers suggested that a range of one millisecond for a collision with concrete to somewhere around six milliseconds for dirt would be reasonable to assume.

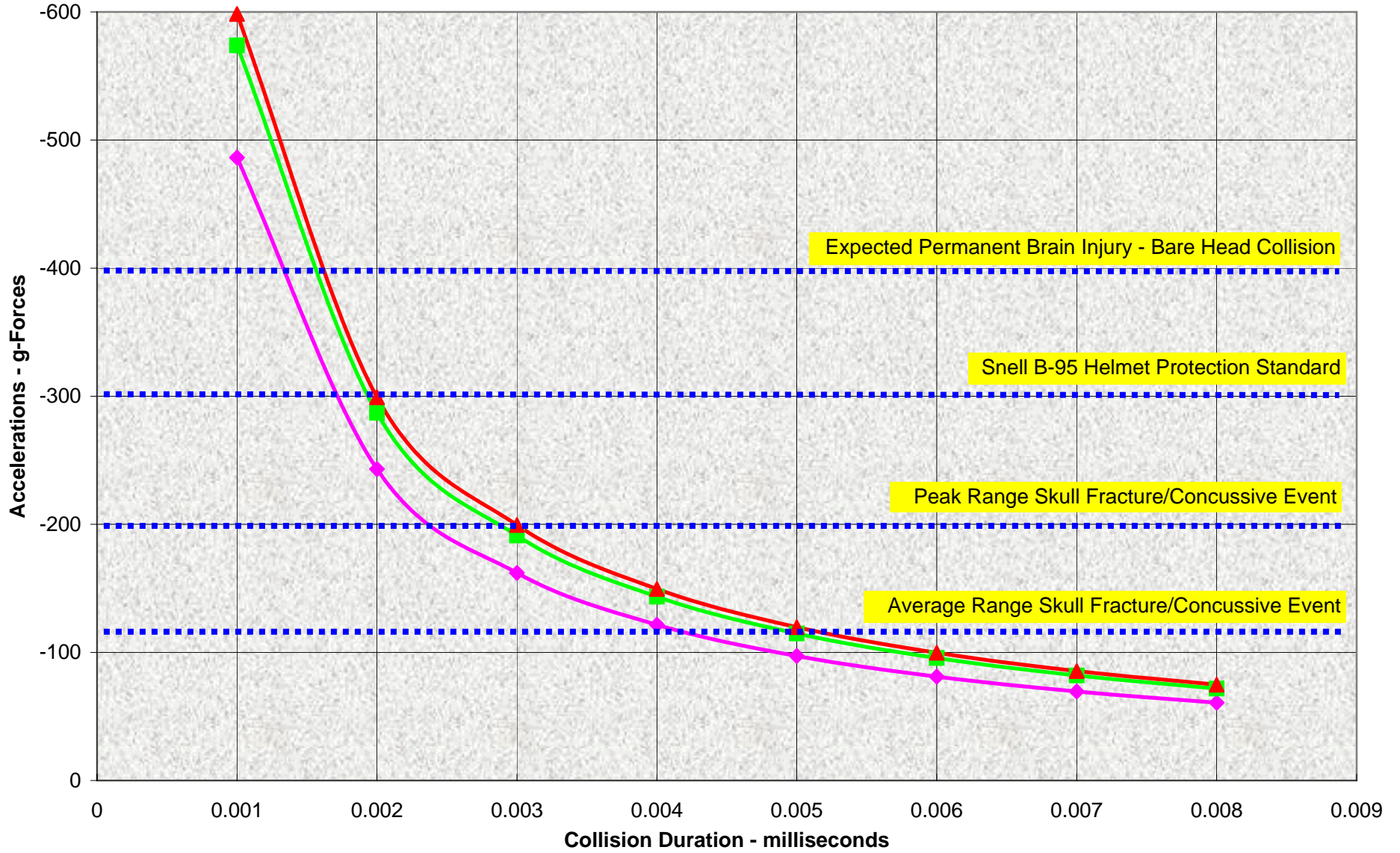
The resulting chart “Head-Fall Velocity Correlated to g-Forces and Head-Injury Benchmarks” shows considerable variations in gravities experienced when colliding with different surfaces. In some instances, if the collision duration is increased by as little as one millisecond, the g-forces decrease substantially.

The energy created by the head colliding with the ground must be managed by the helmet to protect the head and brain. The chart “Impact Energy Correlated to Helmet Standard” shows a heavier head with faster impact velocity will have more energy upon impact than a lighter, slower-falling head. The helmet crushes at impact and converts kinetic energy into mechanical energy, which increases the time it takes for the head to stop. In other words, a slow stop is better than a fast stop. The Snell Helmet Standard B-95 specifies that for a helmet to pass, it must be able to absorb 110 joules of energy when colliding with a flat surface. My test results show that a helmet meeting this standard would have more than likely protected any of my “victims.”

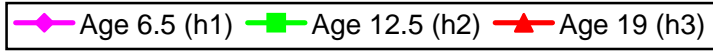
Tab-Fall Time and Simulated Head Velocity



Head-Fall Velocity Correlated to g-Forces and Head-Injury Benchmarks

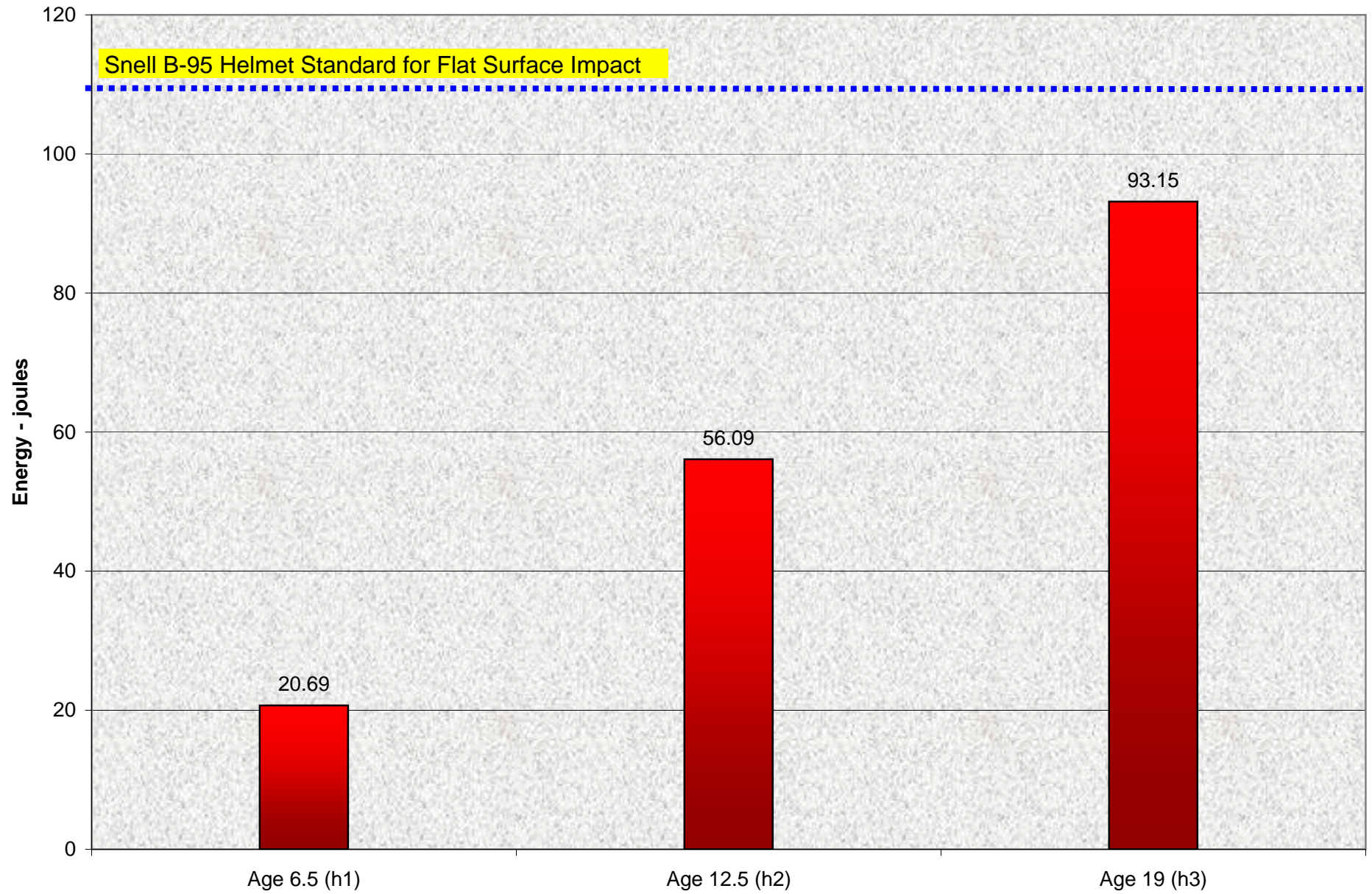


← Harder Surface



Softer Surface →

Impact Energy Correlated to Helmet Standard



VIII. Conclusion

The results from the experiment showed that the velocity, force, and energy created in a simple tip-over fall onto a hard surface are more than great enough to cause a serious head and/or brain injury to a cyclist not wearing a helmet. Even collisions with softer surfaces produced potentially hazardous forces.

The next course of action, to improve accuracy, would be to construct a new HFS that includes a head and body that would simulate human proportions and weight distribution. Also, one should add an accelerometer and test on different surfaces, such as concrete and dirt. This would be the most accurate way to simulate a cyclist tipping over in the real world.

My test results and research convincingly suggest that a helmet is a good safety precaution regardless of ground speed.

IX. Application

The general public will benefit from my research by learning that it does not solely matter how fast you ride when considering if a helmet should be worn. This research applies to any sport that involves the risk of a fall from almost any height. It is no longer valid to use the excuse that "I don't ride fast enough to need a helmet." I hope this research will make an *impact* on peoples' decision to wear a helmet or not.

X. Bibliography

X.a. Primary Sources:

Beck, Kirby, Trainer, International Police Mountain Bike Association. [phone], 2/21/05

Contributed to an article stating that the forces experienced in a simple tip over fall are three to four times the amount necessary to cause a fatal brain injury. He suggested interviewing Randy Swart of the Bicycle Helmet Safety Institute.

Becker, Ed, Executive Director, Snell Memorial Foundation, science fair project. [online, phone] kms@slvoutdoor.com, ed@smf.org, 1/19/05 thru 3/2/05

Provided extensive information on how researchers determined peak g criterion for helmet standards. Discussed the connection between g-forces and head injuries, impact velocity, deformation, and explained the race between a helmet crushing and the head stopping. He described that g-forces are related to stop time (collision duration) and helped define the assumed ranges for a typical human head colliding with various surfaces.

Burt, Eric, Owner, Kristi Mountain Sports. [interview] (719) 589-0432, 8/31/04 thru 03/10/05

Recommended the three age groups and bicycle sizes used; and explained common bike fit standards to develop the Anthropometrical Model and Head-Fall Simulator.

Cryer, John, P.T., Physical Therapist. [phone] (719) 589-0802, 2/11/05

Verified the anthropometrical data for a 19 year old would be reasonable to use for the adult head height.

Emmons, Dr. Randy, Professor of Physics, Adams State College.
[phone, online, interview] kms@slvoutdoor.com,
rwemmons@adams.edu, 2/2/05 thru 3/5/05

Helped to develop the testing method, supplied the Photogate Timer, and explained physics equations and calculations to determine velocity, force and energy.

Pietrzak, Chris, Helmet Designer, Specialized Bicycle Components,
05 science fair question. [online] kms@slvoutdoor.com,
Chris.Pietrzak@specialized.com, 1/18/05 thru 2/8/05

Described the standards they use to certify helmets and suggested contacting the Snell Foundation.

Richter, Eric, Sr. Marketing Communications Manager, Giro Helmets,
helmet science fair questions. [online] kms@slvoutdoor.com,
erichter@bellsports.com, 2/7/05 and 2/9/05

Stated that there are many variables involved when correlating specific head trauma with various speeds and energies. Suggested contacting a biomechanicist and a neurosurgeon for more information.

Swart, Randy, Director, Bicycle Helmet Safety Institute, science fair
discussion. [phone, online] kms@slvoutdoor.com,
randy@helmets.org, 2/21/05 thru 2/23/05

Supplied background information on a Wayne State University study conducted to determine what a fatal peak g-force would be. Researchers found 400 g's would cause some form of permanent brain damage. That lead to adopting the 300 g threshold as a starting point for developing helmets.

Zinn, Lennard, Technical Writer, Velo News, bicycle science fair
questions. [online] kms@slvoutdoor.com, l.zinn@comcast.net,
1/15/05

Suggested contacting Eric Richter of Giro Helmets as a helmet expert.

X. Bibliography

X.b. Secondary Sources:

About, Sir Isaac Newton.

<<http://inventors.about.com/library/inventors/blnewton.htm>>

History and general information about Newton's laws describing gravity and motion.

Bicycle Helmet Safety Institute, A Compendium of Statistics from Various Sources. <<http://www.helmets.org/stats.htm>>

In-depth statistics about all bicycle related injuries (not just head injuries).

-----, Bicycle Helmet Standards.

<<http://www.helmets.org/standard.htm>>

Background information and comparison of many current published helmet standards.

-----, Bike Helmets Made Simple. <<http://www.helmets.org/plain.htm>>

Overview on how a helmet works and why wear one; also discussed the different parts of a helmet and their purpose

-----, Calculations for Understanding Standards.

<<http://www.helmets.org/dropcalc.htm>>

Table that correlated mass, energy, velocity, and height for any drop scenario.

-----, The Effectiveness of Bicycle Helmets: A Review.

<<http://www.helmets.org/henderso.htm>>

Extensive research paper exploring all areas of helmet use; injuries, crash characteristics, biomechanics of head injury, and effectiveness of bicycle helmets.

-----, Foams Used in Bicycle Helmets.
<<http://www.helmets.org/foam.htm>>

Examples and discussion about different foams used in helmets, various thickness, and other experimental materials.

-----, What is a "g". < <http://www.helmets.org>

Described in detail what a g-force is and how it is used in evaluating helmet effectiveness.

Bothamley, Jennifer. Dictionary of Theories. Canton: Visible Ink Press, 2002, Pg 274-275.

Stated Newton's three laws in their original form.

Brain Injury Resource Center, Brain Injury.
<<http://www.headinjury.com/tbitypes.htm>>

Extensive background information on the topic of brain injuries, types, signs, and symptoms.

Cuntell, John D. and Kenneth W. Johnson. Physics. New York: John Wiley & Sons, Inc., 1989. Pg 28, 31, 45, 157.

Examples of problems and formulas used to calculate accelerations. Explained the relationship between mass, energy, force, and velocity.

Gurdjian, E. S., M. D. Et al. Tolerance Curves of Acceleration and Intracranial Pressure and Protective Index in Experimental Head Injury. Detroit: Wayne State University, 1966.

Researchers used human cadavers and dogs to determine the relationship between forces and concussive events. It also supplied information about peak, average, and sustained g-forces that the human head could tolerate.

Kerighbaum, Ellen and Katharine M. Barthels. Biomechanics.
Minneapolis: Burgess Publishing Company, 1985, Pg all.

Supplied numerous examples of humans in various activities and the forces involved in those activities. In addition, was a source for concepts and formulas related to human movement.

National Institute of Standards and Technology, AnthroKids - Anthropometric Data of Children.
<<http://www.itl.nist.gov/iaui/ovrt/projects/anthrokids/data1977/description.htm>>

Source of anthropometrical (human measurement) data for ages 2 to 19.

Oberg, Erik. Et al. Machinery's Hand-Book 22nd Revised Edition.
New York: Industrial Press Inc, 1984.

Supplied formulas to solve right triangle problems for anthropometrical modeling and was a reference for common abbreviations.

Prentice Hall Science. Motion, Forces, and Energy. Upper Saddle River: Prentice Hall, 1997, Pg 41 – 57.

Explained Newton's laws of gravitation and the connection to motion, forces, and energy.

Snell Memorial Foundation, Inc., 1995 Standard for Protective Headgear 1998 revision For Use in Bicycling.
<<http://www.smf.org/pdf/b95rev.pdf>>

Non-profit organization dedicated to developing and publishing helmet standards. This document defined testing procedures, benchmarks, materials, helmet coverage, retention systems, and finish.

XIV.a. Formulas

The following are the major physics formulas used to calculate various values within the project.

Determine tab velocity on Head-Fall Simulator arm

$$v = \frac{d}{t}$$

Theoretical fall velocity at impact of the HFS “head”

$$v = \ell \sqrt{\frac{2mga (\cos(5^\circ) - \cos(\theta))}{I}}$$

* Formula Courtesy of Dr. R. Emmons

Calculate accelerations (g-forces) at impact

$$a = \frac{v_f - v_i}{t}$$

* Formula Courtesy of Dr. R. Emmons

Determine amount of kinetic energy in joules of “victim’s” head at impact

$$KE = \frac{1}{2}mv^2$$

Determine equivalent straight drop height – (fall-out-of-bed scenario)

$$h = \frac{e}{mg}$$

a accelerations
a center of gravity
d distance
g gravity (acceleration)
I moment of inertia
KE kinetic energy

l length
m mass
t time
v velocity
V_f final velocity
V_i initial velocity

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