FIXED-SITE AMUSEMENT RIDE INJURY SURVEY, 2007 UPDATE

Prepared for
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Preface

This report presents the results of work done by the National Safety Council, Research and Statistical Services Group, under contract to the International Association of Amusement Parks and Attractions. It includes estimates by the Council for calendar years 2003 through 2007. The Council's work is an extension of, but independent of, the estimates made for 2001-2002 by Heiden Associates, which are included here for reference and reported more fully in the June/July 2003 issue of *Injury Insights* (Heiden & McGonegal, 2003).

FIXED-SITE AMUSEMENT RIDE INJURY SURVEY, 2007 UPDATE

Since 2001 the International Association of Amusement Parks and Attractions (IAAPA) has sponsored an annual survey to collect and analyze ride, attendance, and patron injury data from facilities that operate fixed-site amusement rides. The IAAPA survey was undertaken to gain perspective on fixed-site amusement ride injuries in the United States. The surveys include amusement and theme parks, tourist attractions, and family entertainment centers. The results of these surveys are presented below.

Facilities were asked to report attendance and ridership as well as the number of patron injuries. Separate attendance-based and ridership-based analyses were performed and are shown in Table 2. To be consistent with the estimates previously reported for 2001-2002, the "Survey Highlights" are shown in Table 1. Estimated attendance in 2007 was less than 0.5% higher than in 2006 and estimated ridership was up 1.1%.

Table 1. Survey Highlights

	2001-2002	2003*	2004	2005	2006	2007
Number of Facilities	459	403	403	398	395	395
Estimated Annual Attendance (millions)	302.9	300.4	300.0	300.4	291.7	292.1
Estimated Annual Ridership (billions)	---	1.95	1.81	1.82	1.76	1.78
Estimated Annual Number of Ride-Related Injuries	2,486	2,044	1,637	1,783	1,797	1,664
Injuries per Million Attendance	8.2	7.0	5.2	5.2	6.6	4.6

Source: 2001-2002, Heiden & McGonegal (2003). 2003-2006, National Safety Council estimates based on fixed-site amusement ride injury surveys.
*Changes in the estimating method beginning with 2003 affect comparability with the 2001-2002 survey.

Not all facilities were able to report both attendance and ridership and therefore there were differences in the selection of facilities used in each analysis. Table 2 indicates that the ridership-based estimates of ride related injuries compared to attendance-based estimates are 355 lower in 2007 (1,664 vs. 1,309), 251 lower in 2006 (1,797 vs. 1,546), 70 lower in 2005 (1,713 vs. 1,783), 11 higher in 2004 (1,648 vs. 1,637), and 90 lower in 2003 (1,954 vs. 2,044). The changes in exposure noted above had a corresponding affect on the resulting injury estimates. Nevertheless, the distributions of injuries by ride type and severity obtained from the ridership-based estimates were very similar to the distributions obtained from the attendance-based estimates.

Table 2. Attendance-Based vs. Ridership-Based Injury Estimates, 2003-2007

	2003	2004	2005	2006	2007
Attendance-Based					
Estimated Annual Number of Ride-Related Injuries	2,044	1,637	1,783	1,797	1,664
Injuries per Million Attendance	7.0	5.2	5.2	6.6	4.6
Ridership-Based					
Estimated Annual Number of Ride-Related Injuries	1,954	1,648	1,713	1,546	1,309
Injuries per Million Patron-Rides	1.0	0.9	0.9	0.9	0.7

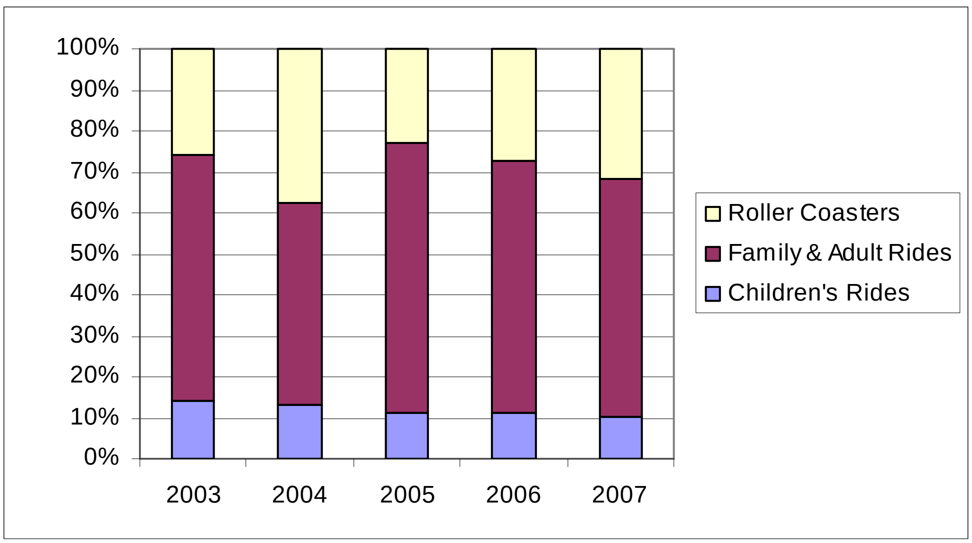
Source: National Safety Council estimates based on annual fixed-site amusement ride injury surveys.

Ridership is a better measure of exposure to risk than attendance because injuries on rides is the outcome of interest. Parks with similar attendance may have much different ridership numbers because of differences in the number and kinds of amusement rides provided. The results reported below are based on the ridership analysis, which is shown in Table 3. This analysis provides additional results that were not available from the 2001-2002 survey.

- The estimated injury total is down 15.3% in 2007 compared to 2006 (1,309 vs. 1,546).
- The rate of injuries per million patron-rides was down 22.2% in 2007 compared to 2006 (0.7 vs. 0.9)
- Compared to 2003, both the estimated number of injuries and the rate in 2006 were down.

As shown in Figure 1, about three fifths of the injuries in 2007 occurred on family and adult rides compared to about the same portion in 2006 and two thirds in 2005. Roller coasters accounted for 31.8% of the injuries in 2007 – more than in 2006, 2005, and 2003 but less than in 2004. Injuries associated with children's rides decreased steadily from 14.2% in 2003 to 11.2% in 2005, remained basically unchanged at 11.4% in 2006, and decreased again to 10.2% in 2007.

Figure 1. Proportion of Injuries By Ride Type, U.S., 2003-2007



Source: National Safety Council estimates based on annual fixed-site amusement ride injury surveys.

In 2007, the injury rate for family and adult rides was 0.7 per million patron-rides, compared to 0.9 for roller coasters and 0.5 for children's rides. The difference between the injury rate for children's rides and family and adult rides is statistically significant as is the difference between the injury rates for children's rides and roller coasters. The difference between the family and adult and roller coaster injury rates was also statistically significant.

About 2.7% of the injuries were reported to be "serious," which means an injury that results in immediate admission and hospitalization in excess of 24 hours for purposes other than medical observation. The remaining 97.3% were other than serious. The proportion of injuries that were serious in 2007 was lower than in previous years. The rate of serious injuries per million patron-rides was 0.02, down from 0.1 for each of the previous three years.

Table 3. Summary of Estimated Fixed-Site Amusement Ride-Related Injuries, U.S., 2003-2007 (based on ridership)

Year	Characteristic	Total	Children's Rides	Family and Adult Rides	Roller Coasters	Total	Serious Injuries	Other Reportable Injuries
2003	Estimated Number of Injuries	1,954	277	1,173	504	1,954	106	1,848
	Percent	100.0%	14.2	60.1	25.8	100.0%	5.4	94.6
	Injuries per Million Patron-rides	1.0	1.2	1.0	1.0	1.0	0.1	1.0
2004	Estimated Number of Injuries	1,648	219	806	613	1,648	132	1,516
	Percent	100.0%	13.3	49.5	37.2	100.0%	8.0	92.0
	Injuries per Million Patron-rides	0.9	1.0	0.8	1.2	0.9	0.1	0.8
2005	Estimated Number of Injuries	1,713	192	1,131	390	1,713	132	1,582
	Percent	100.0%	11.2	66.0	22.8	100.0%	7.7	92.3
	Injuries per Million Patron-rides	0.9	0.8	1.0	0.9	0.9	0.1	0.9
2006	Estimated Number of Injuries	1,546	177	943	426	1,546	135	1,411
	Percent	100.0%	11.4	61.0	27.6	100.0%	8.7	91.3
	Injuries per Million Patron-rides	0.9	0.7	0.9	1.0	0.9	0.1	0.8
2007	Estimated Number of Injuries	1,309	134	759	416	1,309	35	1,274
	Percent	100.0%	10.2	58.0	31.8	100.0%	2.7	97.3
	Injuries per Million Patron-rides	0.7	0.5	0.7	0.9	0.7	0.02	0.7

Source: National Safety Council estimates based on annual fixed-site amusement ride injury surveys.
Note: Totals may not equal sum of parts due to rounding.

Survey Response

Of the 395 eligible facilities in 2007, 138 provided some or all of the data requested. The number of facilities responding was similar to previous years. The respondents used in the analyses represented about 67% of the estimated total annual attendance and about 66% of estimated total rides taken at all facilities.

Data from 125 facilities were used for the 2007 attendance-based estimates compared to 124 for 2006, 117 for 2005 and 124 for 2004. Data from 104 facilities were used for the 2007 ridership-based estimates compared to 97 for 2006, 90 for 2005 and 99 for 2004. It was impractical to find a single set of facilities that reported all data (attendance, ridership, and injuries) for all years as that would have reduced the reliability of the estimates.

Differences with NEISS

National statistics on fixed-site amusement ride injuries are also available from annual reports issued by the U.S. Consumer Product Safety Commission (CPSC; e.g., Levenson, 2003 and Levenson, 2005). However, the IAAPA survey and the CPSC estimates are based on different definitions, data sources, and methodological approaches so direct comparisons are not appropriate.

2003-2007 Methodology

The National Safety Council conducted the survey using a master list of amusement/theme parks, family entertainment centers, and tourist attractions thought to have fixed-site rides. The master list was prepared in consultation with IAAPA and Amusement Industry Consulting, Inc. The survey consisted of a notification letter, a package of reporting information mailed one week later, and a follow-up postcard mailed one week after the reporting package. After the mailings, IAAPA volunteers made follow-up telephone calls and sent e-mails to IAAPA member facilities and some nonmember facilities. Injury rates based on the reporting facilities were used to estimate national totals. (See also "Survey Response" above.)

2001-2002 Methodology

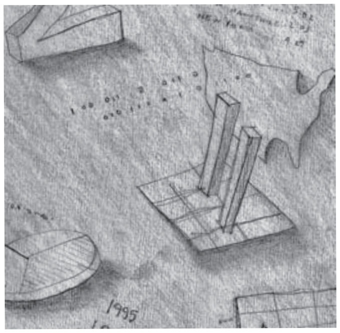
In 2001 and 2002 IAAPA mailed survey questionnaires to members previously identified as having fixed-site amusement rides. IAAPA retained Heiden Associates, Washington, DC, to analyze the survey results. Using the IAAPA survey results and other data, Heiden Associates estimated the number of U.S. facilities with one or more fixed-site amusement rides and the injury totals and rates.

References

Heiden, E.J., & McGonegal, S. (2003). 2001-2002 fixed-site amusement ride injury survey analysis. *Injury Insights*, June/July 2003.

Levenson, M.S. (2003). *Amusement ride-related injuries and deaths in the United States: 2003 update*. Bethesda, MD: U.S. Consumer Product Safety Commission.

Levenson, M.S. (2005). *Amusement ride-related injuries and deaths in the United States: 2005 update*. Bethesda, MD: U.S. Consumer Product Safety Commission.



National Safety Council
Research & Statistical Services

Injury Insights™

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2001-2002 Fixed-Site Amusement Ride Injury Survey Analysis

Edward J. Heiden, Ph.D. and Stephen McGonegal, Heiden Associates, Inc.

In this issue:

National statistics on fixed-site amusement ride injuries are currently available from annual reports issued by the U.S. Consumer Product Safety Commission (CPSC). To gain additional perspective on fixed-site amusement ride injuries in the United States, the International Association of Amusement Parks and Attractions (IAAPA) has sponsored an annual survey program to collect and analyze ride, attendance, and injury data from its members. Results now available from the 2001 and 2002 annual surveys provide a more detailed picture of fixed-site amusement ride injuries—and of injuries specifically associated with roller coasters and children's rides. Over time, the industry hopes that its annual data collection program will provide a comprehensive and accurate picture of safety trends within the U.S. fixed-site amusement sector.

In each of the past two years, IAAPA has mailed survey questionnaires to 268 members previously identified as having fixed-site amusement rides. Respondents were asked to report all injuries requiring treatment beyond ordinary first aid that were sustained by patrons when entering, exiting, riding, or otherwise involved with a fixed-site amusement ride. IAAPA retained Heiden Associates to analyze the survey results. Based on the 2001-2002 data provided by survey participants, we estimate that there are about 2,500 ride-related injuries each year associated with fixed-site amusement rides located at theme parks, amusement parks, family entertainment centers, and a wide variety of other facilities. This estimate and the annual CPSC estimates of amusement ride injuries are based on different data sources and methodological approaches. However, they both show that the number of injuries is low relative to the approximately 300 million people attending amusement parks and attractions with fixed-site rides each year (see our comparison of injury risks presented in Table 1).

Table 1
Highlights from Analysis of 2001-2002 IAAPA Member Surveys

Number of Facilities with Fixed Site Rides	459
Average Annual Attendance (million)	302.9
Annual Number of Ride-Related Injuries	2,486
Injury Risk per Million Visitors	8.2

Nearly 200 IAAPA members responded to at least one of the first two annual surveys. Of the respondents, 177 reported operating at least one fixed-site amusement ride. The results include data from all but two of the 48 U.S. attractions included on the annual *Amusement Business* list of "Top 50 North American Amusement/Theme Parks" (the remaining two parks are located in Canada). Total annual attendance for U.S parks in the "Top 50" is estimated at 167 million, or about 55% of overall U.S. attendance at facilities with fixed site rides. Reports were also provided by a diverse cross-section of smaller amusement parks and other attractions that operate one or more fixed-site amusement rides. Some of these respondents provided data for both annual surveys; others reported results for only one of the two years covered by these estimates. (An expanded description of the survey results and methodology is available from the authors on request).

Using the IAAPA survey results and other data, we estimate that there are about 460 U.S. facilities with one or more fixed-site amusement rides. Annual total attendance in 2001-2002 for this sector is estimated at 303 million. Based on the attendance and injury numbers, we estimate that there are about 2,500 fixed-site amusement ride injuries annually, or just over eight per million visitors.

Our estimate of fixed-site amusement ride injuries is below those previously available from the CPSC National Electronic Injury Surveillance System (NEISS), which estimated that there were 6,700 fixed-site ride injuries in 2001 that required emergency room treatment. Several factors may contribute to the difference between the two estimates:

1. The NEISS annual injury estimates are derived from emergency room injury reports from about 100 of the

Letter from the Editor

This second anniversary issue of *Injury Insights* is a special issue focusing on fixed-site amusement ride safety. Because popular media have covered this issue periodically over the past few years, we anticipate a significant amount of interest in this topic and invite informed, data-driven comment and research submissions that add further insight into the research presented in this issue. Send correspondence to thomasj@nsc.org.

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nation's more than 5,000 hospitals with ER facilities. (In contrast, the IAAPA survey estimate is based on a sample that includes more than 30% of the fixed-site amusement locations, and more than 60% of the combined total attendance at all U.S. facilities.) The NEISS system is designed to track injuries that are generally distributed across the U.S. population, such as those associated with bicycling, lawn mowers, and garage doors. However, it may be less suitable for location-specific sources such as fixed-site amusement rides. This may account for the wide range of statistical uncertainty attached to the CPSC estimate. The CPSC August 2002 Update reports a 95% confidence interval of +/- 43% around its overall amusement ride injury estimate.

2. The CPSC classification of amusement rides as fixed-site, mobile, inflatable, or not an amusement ride is based on short narratives provided by participating NEISS hospitals. In fact, nearly half (3,200 of 6,700) of the CPSC fixed-site amusement ride injury estimate in 2001 comes from allocating "unknown type of ride" cases.
3. The survey-based estimates rely on IAAPA member reports for our study, which may be subject to some of the limitations inherent in this type of self-report survey. For example, a 1997 Minnesota Department of Labor and Industry study found that occupational injury estimates based on self-reported data were about 15% lower than those obtained from workers compensation claim files. Similar variations could be present in the IAAPA member survey data.

On the other hand, the IAAPA survey-based estimate is somewhat higher than the annual injury estimates that can be developed from amusement ride injury reports available from state regulatory authorities in California and Texas. We estimate that amusement parks and other attractions in these two states account for 23% of combined annual attendance at all U.S. facilities with fixed-site amusement rides. Based on the injury data collected from the state regulatory agencies in California and Texas, it would be reasonable to project that there are about 1,800 injuries annually associated with U.S. fixed-site amusement rides, or about 28% fewer than the 2,500 estimated from the IAAPA survey data.

Our analysis of the IAAPA survey responses shows that a relatively small number (76 annually) of fixed-site amusement ride injuries resulted in overnight hospitalization for treatment. Fatalities were rare: there were two fixed site amusement ride-related fatalities in 2001 and one in 2002.

The IAAPA member participants also provided a breakout of injuries for three types of fixed-site amusement rides: children's ("kiddie") rides, adult/family rides, and roller coasters, data that have been heretofore unavailable. Separate weighting factors based on survey response rates were developed from the results for Top 50 parks and for three categories of smaller facilities: amusement/theme parks, family entertainment centers, and tourist attractions. For each category, the injury totals reported in the survey were divided by the percentage of known U.S. facilities with qualifying rides that provided survey responses. Using this procedure, we estimate that children's rides accounted for about 10% of all fixed-site ride injuries, while roller coasters accounted for 26% of the total injuries (see Table 2).

Table 2
2001-2002 Annual Injury Estimates by Type of Ride

Type of Ride	Survey Reported Injuries	Percent of Total	Estimated Annual Injuries	Percent of Total
Kiddie Rides	118	7%	241	10%
Adult/Family Rides	960	61%	1,591	64%
Roller Coasters	508	32%	654	26%
Total	**1,586**		**2,486**	

In addition, our analysis found that injury risk of fixed-site amusement rides (estimated at eight per million visitors) compares favorably with those of other common recreational and sporting activities. Using participation data from the National Sporting Goods Association (NSGA) and injury estimates from the CPSC NEISS database, we determined that fixed-site amusement ride injury risk is 10 to 100 times lower than for most common recreational and sporting activities. The most appropriate basis for comparing risk estimates is "participant days," which measures injury risk in terms of the number of daily visits to amusement parks and attractions with rides and the annual number of days on which participants engage in various other recreational and sporting activities.

Table 3
Injury Risk for Common Recreational Activities

Activity	Injuries/Million Participant Days
Basketball	876
Football	864
Soccer	343
Baseball	302
Skateboarding	286
Volleyball	273
Ice Hockey	249
Bicycling	232
Water Skiing	226
In-Line Skating	161
Racquetball (Squash, or Paddle Ball)	113
Fishing	88
Tennis	88
Golf	68
Swimming	65
Bowling	39
Badminton	24
Shuffleboard	14
Table Tennis	14
Camping	10
Exercising w/ Equipment	9
Billiards/Pool	8
Fixed-Site Amusement Rides	8
Darts	3

Sources: NSGA, CPSC, IAAPA, Heiden Associates

The activities analyzed include basketball, football, roller skating, and soccer. Fishing and golf are also considerably riskier than fixed-site amusement rides. Amusement ride risk is closest to activities such as: shuffleboard and table tennis, camping, exercising with equipment, and playing billiards.

The 2001-2002 member self-report

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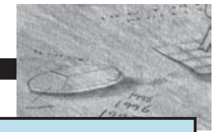

Brain Injury Association Completes Review of The Correlation Between Brain Injury and Roller Coaster Rides

Nils Roberts Varney, Ph.D

In the Fall of 2001, U.S. Representative Edward Markey (D-MA) and Bill Pascrell, Jr. (D-NJ), along with 12 additional Members of Congress, requested that the Brain Injury Association of America (BIAA) research the most current information on the safety of amusement park rides, mainly roller coasters, as there were concerns about potential brain injury related to g-forces on these rides. An independent panel of scientists in the fields of biomechanical engineering, epidemiology, clinical medicine, basic neuroscience, and neurotraumatology, along with an amusement industry expert, was assembled to research the issue.

As part of our research, the Panel reviewed: (1) an assemblage of sometimes anecdotal cases of patients who reportedly sustained cranio-cerebral injury related to roller coaster rides over the past 38 years (a total of 57 cases); (2) the forces on modern roller coasters; (3) relevant codes and standards; (4) amusement industry data and statistics; and (5) the wide-ranging library of scientific research carried out by aerospace, aeronautics, biomedical and military institutions over the last 50 years, some of this g-force research having been preformed by Panel members themselves.

The BIAA released the report in February 2003. In summary, the findings were:

1. "There is evidence that roller coaster rides pose a health risk to some people some of the time, but it is equally evident that the overwhelming majority of riders will suffer no ill effects. Most major categories of at-risk population, such as pregnant women or persons with heart conditions, epilepsy, back or neck injury or prior orthopedic surgery among others, are already warned against riding."
2. There was no comprehensive database or natural history data available. The Panel's review of the 57 cases indicated that the majority of the plausible cases were associated with undiagnosed preexisting conditions such as blood vessel abnormalities, malformations, or aneurysms. *"These are risk groups, like those listed in #1 above, but unknown to the rider. It is unlikely that the rider's physician, much less the amusement ride owners/operators, could have known that these persons were at risk before the fact."*
3. The panel questioned the methodology of existing acceleration measurements; it was also stated *"improvements in precision and relevance probably would not result in accelerometer findings of more than a 20% difference from those already obtained."*

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CPSC Injury Estimates Associated with Fixed-Site Rides

Alan Hoskin

The US Consumer Product Safety Commission (CPSC) reported an estimate of 8,313 non-occupational amusement ride-related injuries treated in hospital emergency departments in 2001 of which 6,704 were associated with fixed-site rides and 1,609 with mobile rides. The 95% confidence interval for the 8,313 estimate was 4,720 to 11,906 injuries.

The CPSC looked at injury trends over time. Because there was a periodic update in the sample of hospitals in 1997, the analysis was based on data from 1997 through 2001. The trend in the *number* of fixed-site ride injuries was found to be marginally statistically significant (p=0.075) and for mobile ride injuries the trend was not statistically significant (p=0.124). However, when adjusted for attendance, the upward trend in fixed site ride injury *rates* was not statistically significant (p=0.152). Data on attendance at mobile rides was not available so rates could not be calculated.

Looking at fixed-site rides only, injuries most frequently involved the shoulder, arm, and hand (42%). The head, including the face and ear, and the trunk, including the neck, each

Estimated Non-Occupational Amusement Ride-Related Injuries, United States, 1997-2001

		Fixed-Site Rides		
Year	**Mobile Ride Injuries**	**Injuries**	**Attendance (Millions)**	**Injuries per Million Attendance**
1997	2,562	5,353	300	17.8
1998	2,751	6,523	300	21.7
1999	2,788	7,629	309	24.7
2000	3,985	6,595	317	20.8
2001	1,609	6,704	319	21.0

Source: Levenson, M.S. (2002). *Amusement Ride-Related Injuries and Deaths in the United States: 2002 Update*. Bethesda, MD: US Consumer Product Safety Commission.

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Safer by Design/Technology in Amusements

T. Harold Hudson

Advances in technology continually transform and improve the way we live, work, and play. This is particularly true of today's amusement industry, where amusement rides, especially roller coasters, have progressively gotten larger, faster and more thrilling yet are smoother and generate lower forces than ever before.

The trend toward more thrilling rides is likely to continue, as the public grows accustomed to current rides (the scary rides of 10 years ago are the mundane rides of today) and demands more for its entertainment dollar. In response, the amusement industry (which includes ride designers, manufacturers, and park owners and operators) uses a sound, logical managerial approach to the design, construction and management of amusement park rides. Technology has provided the basis and means by which great advances have been made in amusement ride design and scale while improving quality and entertainment value. In other words, technology has allowed the industry to meet public demand for more thrilling rides while maintaining and improving comfort and safety.

Although advances in technology have allowed designers to produce taller and faster roller coasters, some have questioned the safety of these advances. A major concern is that the industry is pushing the limit of human endurance, assuming that if the rides are taller and faster, the forces must be higher and therefore more dangerous.

To assume that roller coasters that are taller and faster have higher forces is not precisely correct since speed and height are not the only attributes that determine forces (acceleration levels) on a roller coaster. The overall design of a roller coaster (i.e., the hills, valleys, curves, radius of curvature and speed) determines the forces. Designers and engineers control all of these elements to produce a taller-faster roller coaster with the same or lower forces than older designs. For example:

A. A particular roller coaster design produces 3 g's in the bottom of a drop (vertical curve) when traveling at *50 MPH.*

B. If the design is changed such that the speed is *100 MPH* and the radius of curvature of the drop is increased by four times, the roller coaster will still produce 3 g's in the bottom of the drop.

C. Since … Speed $_{Final}$ = square root of (Speed $_{Initial}$ + 2gh) …where g = acceleration of gravity and h = height, neglecting losses, the height of the above roller coasters would be:
   (1) 50 MPH coaster, approximately 39 feet high
   (2) 100 MPH coaster, approximately 156 feet high

This example follows basic physics, which says that:

A. $F=V^2/R$ or force equals velocity squared divided by radius of curvature.

B. It is easily seen that if the **numerator** (velocity) is squared and the **denominator** (radius of the curve) is increased by four times, then the resultant **force** remains the same for the 50 MPH and the 100 MPH roller coaster.

Thus, speed and height do not necessarily generate higher forces. In fact, high, fast and smooth rides may have substantially lower accelerations than some older, smaller and slower rides.

A dramatic example of improved design is the 360° vertical loop used in looping roller coasters (see Figure). The original looping coasters were constructed with "circular" loops, which had a constant radius. In order for the vehicle to have enough energy (speed) to successfully go over the top of the loop, the speed at the entrance and exit of the loop was very high and the accompanying forces were also high, higher than today's loops. Instead, today's "Clothoid Loop" design, with variable radius of curvature, reduces passenger g loads during the inversion.

Roller coasters and other amusement rides are better today because of advances in technology, including advances in material science, precision manufacturing and computer technology. Modern high-powered computers allow designers to conceptualize, analyze, and calculate every aspect of rides in much more detail than ever before. Computer Aided Design (CAD) and Finite Element Methods (FEM) performed by high-speed computers allow detailed examination of ride safety in all areas, including component strength, force calculations, and ride dynamics. Computers and CAD models allow the designer to make more design iterations and therefore to optimize the design to the fullest extent.

Evidence for this is seen in a study by Exponent Failure Analysis Associ-

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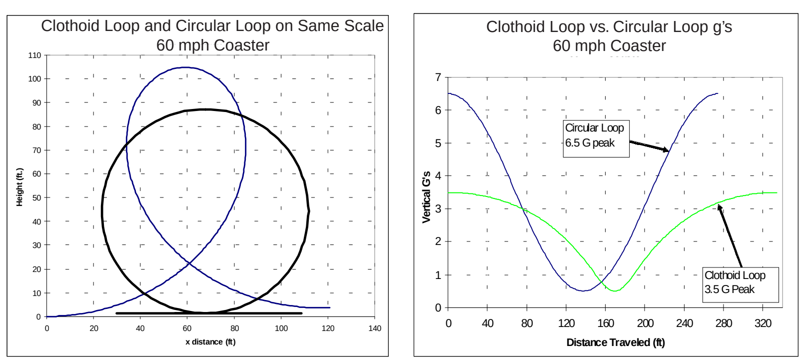
Clothoid Loop versus Circular Loop -- 60 MPH Coaster



(**Note that the force in a modern Clothoid loop is 3.5g peak Vs 6.5g peak in older designs.**)

Roller Coasters, G-Forces, and Brain Trauma: On the Wrong Track?

Douglas H. Smith, MD, and David F. Meaney, Ph.D.

Over the past three years, there has been enormous attention in the general press on the possibility that high g-force roller coasters are inducing brain injury in riders. With an actual number of case reports of brain injuries, members of the U.S. Congress have recently proposed legislation to regulate g-forces induced by roller coaster rides. However, absent from all this fanfare is any sound evidence or analysis directly linking roller coasters with brain injury. This study examined if roller coasters actually pose a risk, and points out a fundamental misconception of how g-forces play a role in the biomechanics of brain injury.

The most powerful roller coasters have g-forces of 4-6 g's; however, it is too simplistic to use g's alone as a measure of the risk of brain injury. Fighter pilots experience 5-9 g's for extended periods (mean of 43 seconds) while roller coasters apply only brief accelerations (<3 seconds) in different directions throughout the ride. Furthermore, high g's of short duration are common and well tolerated in many normal daily activities, such as hopping off a step or plopping into a chair, where 8-10 g's have been measured in volunteers. Accordingly, g-force alone is not a good measure for the risk of brain injury. Rather, rotational head accelerations that can be caused by g-forces are the key to analyzing potential for injury.

Brain injury due to rotational acceleration is dependent on very rapid deformations of the brain, typically within a time span of less than 50 msec.

Actual data from three powerful roller coasters was analyzed and used in a mathematical model to estimate head accelerations induced from roller coasters. G- forces at the seat level were related to the head acceleration of the rider. The mathematical model approximated the head pivoting stiffly about the base of the skull with the acceleration at the seat transferred directly to the junction between the head and neck. The model was designed to determine a worst-case scenario of head acceleration using the maximum peak acceleration over the shortest duration.

Analysis of the temporal g-force data during the course of the three rides revealed that the accelerations in a roller coaster vary side-to-side, fore-to-aft and in the up-down directions throughout the ride. Typically, the up/down (vertical) accelerations are higher than accelerations applied in the fore/aft and side-to-side direction; however, these accelerations are transmitted along the axis of the spine and induce only modest head rotational accelerations. Therefore, no rotational accelerations appear for this case.

The maximum determined accelerations from these three roller coasters were:

Direction	Measured G's	Modeled Rotational Acceleration
Side-to-Side	1.2-4.2	111-387 rad/sec^2
Fore-Aft	1.65-5.4	139-502 rad/sec^2
Vertical	5	N/A

Prior peer- reviewed research has established 4,500 rad/sec^2 as the minimum head rotational acceleration that may cause subdural bleeding and 9,000 rad/sec^2 as the minimum head rotational acceleration that may cause diffuse axonal injury in white matter. Even for a conservative worst-case scenario, the study found that the highest estimated peak head accelerations induced by roller coasters were far below the established levels that may cause head injuries (9 times and 18 times lower, respectively). Accordingly, our findings do not support the contention that current roller coaster rides produce high enough forces to mechanically deform and injure the brain.

In the general press, there seems to be confusion between increased reporting of brain injuries following roller coaster rides and actual increased incidence. To our knowledge, no peer-reviewed studies have found a risk of brain injury by riding newer, more powerful roller coasters, let alone measuring the possible increase in risk factors associated with preexisting vascular malformations.

Although some case reports have described rupture of preexisting vascular malformations in the brains of roller coaster riders, it is unknown whether these individuals had a reduced tolerance to head accelerations. However, it is well recognized that hemorrhage from a preexisting vascular malformations can occur during many everyday life activities that do not mechanically deform the brain. Factors other than head accelerations should always be considered in these cases, such as hypertension from the general excitement and anticipation of the ride.

Drs. Smith and Meaney are at the Department of Neurosurgery and Bioengineering, University of Pennsylvania. A more detailed version of this article was original published in the *Journal of Neurotrauma, Volume 19*(10), 2002.

Invitation for Contributions

Injury Insights readers are invited to send feedback, content ideas, or direct contributions for future issues of the newsletter. Send your comments, ideas, or potential contributions for review to Jonathan Thomas at: thomasj@nsc.org.

Everyday Life Accelerations

Steven R. Arndt, Ph.D., and Robert S. Cargill II, Ph.D.

Throughout the years, there have been many studies examining the forces and accelerations experienced by people associated with the activities of daily living. The results have yielded some surprisingly high numbers, especially when these studies are extended to include contact sports activities. Interestingly, because of the steady 1g acceleration due to gravity, merely changing the body's position relative to the Earth results in swings of 2g's. For example:

- A child on the monkey bars at a playground can go from +1g to –1g in a few seconds.
- Lying on one's side provides the same effect as a 1g lateral acceleration.
- Pulling your head up off a pillow from a supine position requires the same muscle response as +1g frontal acceleration.
- Lying prone on a bed and looking over the edge requires the same muscle response as –1g frontal acceleration.

The data presented in Table 1 illustrate the directional nature of acceleration, which can be simultaneously measured in three dimensions. Table 2 lists some examples of accelerations experienced in everyday life. These data are from a study entitled *"Acceleration Perturbations of Daily Living" by Murray E. Allen, MD, et al. published in Spine (Nov. 11, 1994).* The acceleration data were obtained from a head mounted 3-axis accelerometer sampled at 500 H_z. The x-axis was directed forward, the z-axis was directed downward, and the y-axis was directed to the right (see Table 1).

Table 1

Event	Description	Major Axis Acceleration	Total Acceleration Magnitude
Head Bob	Seated; passively drop head backward as if falling asleep	1.4 g_x	2.2 g
Sit Down	Routine sit down into a kitchen chair from standing position	1.0 g_z	2.5 g
Sneeze	Sniff finely ground pepper into nostrils; uninhibited sneeze	1.8 g_z	2.9 g
Cough	Simulated non-exaggerated cough	1.1 g_x	3.5 g
Hop Off Step	Hop off 20 cm step, land on both feet	4.6 g_z	8.1 g
Plop In Chair	Plop passively backward into low-backed office chair.	4.4 g_z	10.1 g

Gravity is not included in the Z direction numbers; to compare with amusement rides, 1g should be added.

Table 2

Event	Description	Major Axis Maximum Acceleration	Duration
Pogo Stick	Subjects jump up and down as many times as possible in 30 seconds.	4.5 g_z	0.19 seconds
Pillow Strike	Subjects were struck on the back of the head with a common foam pillow.	28.1 g_x	0.01 seconds
Sneeze	One subject was able to produce an uninhibited sneeze.	3.9 g_x	0.83 seconds
Swing	Commercial swing with 15 ft. overhead crossbar and a rigid seat supported by chains.	2.7 g_x	1.74 seconds
Spinning on Tire Swing	Playground type tire swing with 15 ft. overhead crossbar and tire attached at three points such that plane of tire is horizontal.	2.3 g_z	26.16 seconds
Falling Down	Subjects fall forward to knees, chest and stomach onto exercise mat.	16.3 g_x	0.13 seconds

Gravity is not included in the Z direction numbers; to compare with amusement rides, 1g should be added.

A more recent study performed by Exponent Failure Analysis Inc. as part of a larger research project entitled, "*Investigation of Amusement Park and Roller Coaster Injury Likelihood and Severity," August 9, 2002,* shows similar results. These tests used nine subjects between the ages of 14 and 41 and measurement equipment similar to the Allen, et al. test. Specifically the findings were as shown in Table 2.

In order to compare these tests with existing data for roller coasters, the results (falling down, pogo stick, sneeze and pillow strike) were also analyzed using the National Highway Traffic Safety Administration (NHTSA) Head Injury Criteria (HIC) analysis software. The results are shown in Table 3.

Table 3

Event	HIC Score*
Pillow Strike	22.6
Falling Down	15.2
Pogo Stick	1.3
Sneezing	0.5

*The HIC is designed to be an injury metric for the prevention of serious to fatal brain injury and skull fracture. The tests on which HIC is based are "hard" impacts to the head, generally with durations of 10 msec or less. However, HIC has been used to evaluate the effectiveness of vehicle interior padding, airbags, bicycle helmets and playground ground-cover materials. The usefulness of HIC in regard to everyday life accelerations and roller coasters accelerations is unknown.

The data in the Exponent study were collected in a way that they could be directly compared to the existing data for head accelerations recorded on a group of roller coasters. By comparison, the HIC scores on a group of 71 modern roller coasters including looping coasters, wooden coasters, and steel coasters range from a low of 0.2 to a high of 9.4. This analysis demonstrates that the HIC (and thus the head accelerations) experienced by properly seated and restrained roller coaster riders, on this sample of roller coasters, are comparable to or lower in severity than the accelerations experienced

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Injury Survey Analysis

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surveys sponsored by IAAPA provide a more detailed picture of injuries in the fixed-site amusement ride sector. These results also provide baseline numbers that should, when similar data are collected over time, begin to provide a more accurate and complete picture of trends in fixed-site amusement ride injuries than is currently available.

Dr. Heiden is President of Heiden Associates. Stephen McGonegal is a Senior Research Associates at Heiden Associates. For more details about this research, contact Edward Heiden at eheiden@heideninc.com

Brain

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4. *"The accelerations experienced by roller coaster riders are far below those tolerated by healthy subjects in experimental testing."* The highest roller coaster acceleration levels are 6 g's for 1 second. *"…Significant research has been done on healthy individuals regarding the level of sustained acceleration at which blackout can occur and the lowest reported threshold is 5.5 g's over a period of 5 seconds. Also, animal and other experimental research regarding serious brain injury suggest a much higher threshold (35 g's or more); however, it is not clear how this threshold applies to the healthy, human population."*
5. *"The conclusion supported to date is that the risk of brain injury from a roller coaster is not in the rides, but in the riders. That is, there are some people we already know should not participate in roller coaster rides. …"*

Roller coaster technology and design is intended to give the rider the most apparent thrill and risk with the least real risk. With a combination of highly specific design for turns, overhead loops, spirals, etc., it is possible to give the rider what feels like a very dangerous ride, but with the physical forces involved being substantially less than the more tame- appearing roller coasters of 20 years ago. The panel pointed out that, *"whether the amusement park industry is interested in health and safety or the bottom line, both goals are met by keeping rides as absolutely well designed and safe as possible."*

The report also listed five recommendations, including potentially useful future research, surveillance methodology, nationwide oversight, self-monitoring, and common sense approach to riding.

Finally, common sense is always important and one of our recommendations was *"Riders are encouraged to use common sense. If your neck hurts, you have been diagnosed with a medical or neurological illness, have had recent surgery or if there has been an abrupt change in your physical status or any other unusual or unexplained symptoms, skip the ride."*

Dr. Varney is Chief of Psychology Service at the Veterans Medical Center, Iowa City, IA. A copy of the full report can be obtained by going to www.biausa.org

CPSC Estimates

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accounted for 19% of injuries. The leg and foot accounted for 14%. More than one third (35%) of the injuries were sprains and strains. Almost one fourth (24%) were contusions and abrasions. Lacerations accounted for 13% and fractures for 7% of the injuries. Ninety-eight percent of the cases were treated and released from the emergency department while 2% were either admitted to the hospital or treated and transferred to another facility.

The CPSC has documented 38 non-occupational deaths associated with fixed-site amusement rides from 1987 through 2002, or about 2.4 per year.

The latest report, *Amusement Ride-Related Injuries and Deaths in the United States: 2002 Update*, was released August 2002 and is available on the CPSC web site (www.cpsc.gov/library/amus2002.pdf accessed June 10, 2003).

Alan Hoskin is Manager of the Statistics Department at the National Safety Council.

Safer by Design

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ates *(Investigation of Amusement Park and Roller Coaster Injury Likelihood and Severity, released in January 2003)*, which reviewed data from 167 roller coasters built between 1970 and 2003. The study concluded that roller coasters built today are taller and faster than their predecessors, but their peak g-forces are no greater and in some cases are actually lower than their predecessors.

Like all engineered products, roller coaster design improves every year. Increases in speed and height are not just due to a desire for more speed and taller coasters, but are made possible by advances in engineering, design and manufacturing technology.

T. Harold Hudson is the President of AAPRA Associates (All About Parks, Rides, and Attractions), a private consulting company that works with a multitude of companies in the amusement industry.

Everyday Life

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during common daily activities. However, these findings cannot predict the likelihood that an individual who has a pre-existing medical condition or has other elevated risk factors will suffer an injury on one of these rides. As the data indicate, the same individual is at least as likely to have suffered the injury had they fallen down, sneezed, or been hit in the head with a pillow.

These studies indicate that the accelerations experienced by the head in activities of daily living were greater than would be intuitively expected and that they are experienced routinely and uneventfully. Still, individuals who have known pre-existing conditions should exhibit the same care in choosing to ride a roller coaster as they would before participating in any activity that may subject them to minor head impacts.

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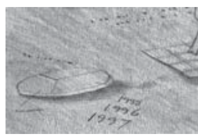

Also the Official Newsletter of the Consortium for Injury and Disability Research

Tips for Visiting an Amusement Park or Attraction

Summer is the time when many people visit their local amusement park or attraction and a bit of thought and planning can go a long way! The International Association of Amusement Parks & Attractions (IAAPA) has compiled some helpful tips that will assist guests in making their visit both safe and fun.

- Dress comfortably, but avoid open-toed shoes and dangling clothing or jewelry. Very long hair should be put up. Protect yourself from the sun with sunscreen and headgear, even on cloudy days.
- Eat normally and take any medications that might be necessary before visiting a park or attraction. Bring medications with you that might be needed during the day. Drink plenty of water and be sure not to skip meals, but only consume food and other beverages, including alcoholic beverages, in moderation prior to enjoying rides. Stop riding before you get excessively tired.
- Observe all posted rules, and follow all verbal instructions given by park personnel or ride operators/attendants.
- Be considerate of others … amusement parks and attractions are unique environments designed for your enjoyment. Don’t let your exuberance ruin the day for you, your friends or neighbors. Queue lines permit guests to experience popular attractions in a comfortable and orderly manner; while in a queue line be especially considerate of others, observe no smoking and other queue line signage, and never break into line, as this is a flagrant violation of basic park policy and a reason for expulsion in most parks and attractions.
- When enjoying rides and attractions, obey posted age, height, and weight restrictions, as well as notices concerning such health matters as heart conditions, back/neck conditions, pregnancy, recent surgery, and high blood pressure. *Always use common sense … if you don’t feel well, if there has been an abrupt change in your physical status, or any other unusual or unexplained symptoms, skip the ride.*
- Remove personal items such as glasses, hats, cell phones, pagers, etc. before boarding a ride. Keep hands, arms, legs, and feet inside the ride at all times, and remain in the ride until it comes to a complete stop and you are instructed by a ride operator/attendant to exit. If a personal item falls outside the vehicle while you are on the ride, ask an operator/attendant for assistance in retrieving it once you have disembarked from the ride. Do not attempt to retrieve any lost articles yourself.
- Always use the safety equipment provided and DO NOT attempt to alter or free yourself from any safety restraint in search of a “better” thrill or an opportunity to show off. Restraints are provided for both your safety and the safety of others.
- Taking an active safety role is especially important in the case of parents with young children: upon your arrival, identify a meeting point in case you are separated during your visit; observe each ride in operation and note the rules regarding age, height and weight; explain appropriate behavior on a ride; and read the rules of the ride together before the child boards the ride.
- Prior to visiting a park or attraction, visit their web site or contact the Guest Relations office for a guide or map that includes general information about rides, entertainment, accessibility information for guests with disabilities, etc.

Source: International Association of Amusement Parks and Attractions.