Playground surfacing and playground injuries

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Reference:

Himmelsbach, J.A. and Shorten M.R. (2003)
Playground surfacing and playground injuries

Pp 71-88 in Sports Surfaces (Eds. B.M. Nigg, G.K. Cole, D.J. Stefanyshyn) Calgary, University of Calgary

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Introduction

The challenges offered by active, exploratory play are important contributors to a child's physical, mental and social development. Adventurous play also carries risks. In the USA, playground related deaths occur more than once per month on average. Each day, hundreds of children require emergency room treatment or hospitalization for playground-related activities.

Since many deaths and severe injuries are the result of falls from playground equipment to the underlying surface, the shock attenuation performance of playground surfacing is expected to have a significant effect on injury risk. Materials that are typically used in playground surfacing include organic loose fills, (e.g. wood chips, bark dust, engineered wood fiber) inorganic loose fills (e.g. gravel, sand, crushed marble) and manufactured products (poured in place rubber/urethane compounds, rubber tiles, etc.). In the USA, awareness of the importance of shock attenuating surfacing in playgrounds is increasing, especially since minimum shock attenuation performance requirements were recently included in the regulations associated with the Americans with Disabilities Act.

This paper reviews recent injury statistics and research related to playground injuries and the role that appropriately designed surfacing can play in the prevention of severe injuries and death due to falls.

Playground Injury and Death Statistics

Measurements and Statistics

Some care is required when interpreting injury and death statistics, especially when comparing the results of different studies. Different definitions of “injury” and different statistical reporting techniques may make direct comparisons misleading.

In order to distinguish between different measures of injury risk, some definitions are useful.

- Exposure: A baseline for measuring risk, including an accounting of the population exposed to injury. For example, we might define an exposure as one child visiting one playground. A measure of exposure is required to determine the both injury risk and relative risk.
- Injury Rate: The number of injuries occurring over a period of time, without reference to exposures.
- Injury Risk: Injury rates relative to an exposure baseline. For example, “One injury per 1000 exposures”
- Relative Risk: A ratio comparing two injury risks. For example, if the injury risk is 0.6 per thousand exposures on the average playground and 1.2 per thousand exposures on playground A then playground A has a relative risk of 2; meaning that injuries are twice as likely to occur on playground A.

Measurements of risk and relative risk provide the most useful and comprehensive documentation of injury data. However, most playground injury statistics do not have exposure baselines, because of the difficulty and expense of collecting exposure information.

The criteria used to define an injury must also be considered when interpreting injury statistics. For example, the US Consumer Product Safety Commission's nationwide surveys of playground equipment-related injuries use emergency room visits as the criterion for recording an injury. Minor injuries treated in Doctor's offices and those not requiring medical attention are therefore not included in these statistics.

Playground Deaths

The US Consumer Product Safety Commission (CPSC) recorded 147 playground equipment-related deaths reported between January 1990 and August 2000 (Tinsworth and McDonald 2001). The CPSC's data included fall-related deaths from only a few states for most years of the survey. Therefore, the fatalities reported can be expected to underestimate the true number. While the exposure baseline of the CPSC's data is not known, the data are valuable nonetheless, since they show the relative frequencies of different kinds of fatal events and can be used to identify sources of risk, if not their relative importance.

Of the reported deaths, 90 (61%) are known to have occurred on playground equipment installed in homes rather than in public playgrounds. The majority of victims were less than ten years old. Younger children were more frequently victims in home settings; older children were more likely to be killed in accidents at public facilities.

The primary cause of playground equipment-related deaths is hanging due entrapment or entanglement with materials tied to the equipment or around the child's neck. Falls accounted for 21% of the recorded deaths, most of which (3/4ths) involved catastrophic head injury. Since new playground equipment is specifically designed to minimize the risk of entrapment and entanglement, the proportion of hanging deaths is expected to decrease over time and fall-related deaths can be expected to increase proportionately.

Playground Injury Rates

The CPSC tracks consumer product-related injuries in the National Electronic Injury Surveillance System (NEISS) database which is based on a sample of 100 hospital emergency rooms located around the USA.. The most recent CPSC report of playground equipment-related injuries and deaths looks at injuries during 1999 (Tinsworth and McDonald 2001). As before, the data do not have an exposure baseline and consequently cannot be used to determine absolute injury risk or relative risk. Nevertheless, the database contains some valuable information about potential sources of risk and the relative frequencies of different kinds of injurious events. During 1999, an estimated 205,850 playground equipment related injuries were treated at hospital emergency rooms, equivalent to one emergency room visit every 1.3 minutes during daylight hours or 7.5 injuries per 10,000 children in the US. Children aged 5-14 were at greatest risk. While fatal events were most likely to occur on home playground equipment, 75% of injuries occurred in public facilities and only 24% on equipment intended for home use.

Accident and Injury Types

About 10% of all accidental injuries to children occur during sport or recreation (Danseco et al 2000;Kersting-Durrwachter and Mielck 2001). Estimates of the proportion of total injuries accounted for by playground accidents varies. (Boyce et al)(1984) found that playground injuries account for only about 4% of the total but these injuries were 1.6 times more likely to be rated “severe” than those caused by other activities. (Bijur et al 1995) found that playgrounds accounted for 13% of the total injuries in children aged 5-9, while 9.6% of injuries to kindergarden children in Southern Germany were from playground falls (Kersting-Durrwachter and Mielck 2001). Studies that restrict their scope to the school environment have found that playground injuries accounted for 61% - 74% of all school injuries (Junkins, Jr. et al 1999; Lenaway et al 1992; Alkon et al 1999).

Recent surveys of playground injury types (Table 1) show that arm and leg fractures are the most common major injury. While head injuries are less common, accounting for 10% of injuries overall, their potential consequences are far more severe.

Table 1: Summary of recent surveys of playground injuries, classified by injury type

Source			Injury Type				
First Author	Year	n	Head Injury	Limb Fracture	Cut, bruise	Sprain, Strain	Other
Macarthur	1999	126	4.8%	47.6%	43.6%	3.0%	
Mayr	1995	338	5.5%	40.8%	37.0%	13.0%	3.7%
Lillis	1997	289	3.0%	28.0%	43.0%	7.0%	10.0%
Waltzman	1999	204	5.0%	61.0%	18.0%	8.0%	6.0%
Pickett	1996	120	2.7%	20.0%	65.0%	3.3%	11.7%
Chalmers	1996	246	3.7%	26.4%	44.3%	7.7%	18.0%
Mack	1997	1868	12.4%	20.5%	----- 53.2% -----		13.9%
Laforest	2000	930	12.0%	55.0%	19.0%	11.0%	4.0%
Bermado	2001	234	42.0%	33.0%			

Table 2: Summary of recent surveys of playground injuries, classified by accident type

Source			Accident Type			
First Author	Year	n	Fall	Collision	Jump	Other
Mayr	1995	103	72.4%	13.9%	5%	8.7%
Mott	1997	330	65.0%	21.0%		14.0%
Mowat	1998	45	80.0%	13.3%		7.7%
Pickett	1996	120	76.7%	11.7%		11.6%
Bermado	2001	234	73.0%			

Playground Hazards

The CPSC's study (Tinsworth and McDonald 2001) reported that 79% of injuries on public playground equipment and 81% of the injuries on home equipment were related to falls. Most injuries (68%) occurred during falls to the surface beneath the equipment, but some (10%) were the result of falling on to other parts of the play structure. A survey of other recently published studies also shows that a majority of injuries (70% on average) are due to falls (Table 2).

Equipment height correlates significantly with severity of injury from falls. Climbing apparatus, slides and swings are associated with more frequent and more severe injuries than other play equipment. Younger children (<5 years) are more often injured on slides (40% v. 26%) while older children are more often hurt on climbing apparatus (47% v. 29%) (Lillis and Jaffe 1997).

While falls and other impacts are the predominant mechanism of playground injury, there are underlying infrastructural and social factors than contribute to the injury rate. These include lack of parental supervision, inadequate surfacing, poor equipment design, lack of maintenance and mixed use of equipment by children of different ages.

Playground surfacing

Since the majority of playground injuries result from falls to the surface, considerable effort has been devoted in recent years to the study, development and promotion of surfaces with appropriate shock attenuation properties.

The trend towards safer, shock attenuating surfaces began in 1975 when the CPSC published its first hazard analysis and safety guidelines for playgrounds. Subsequently, woodchips, gravel, rubber and other "soft" materials began to replace harder surfacing materials like concrete, asphalt, hard packed earth, grass and sand. Compliance with the guidelines has been inconsistent, however. For example, a 1994 study showed that only 15.4% of public playgrounds in Kingston, Ontario, Canada complied with national standards (Pickett et al 1996). Similar findings have been reported in Atlanta, and Montreal. In 1993, a random sample of 25% of Boston's playgrounds didn't contain a single impact-absorbing surface (Bond and Peck 1993). "Playing It Safe", the 2002, Sixth Nationwide Survey of Public Playgrounds, found 75% of public playgrounds have inadequate safety surfacing (U.S.PIRG and Alison Cassady or Liz Hitchcock). This figure has improved by 5% since the 2000 survey was published.

Shock Attenuation Performance Criteria

The current Consumer Product Safety Commission (2000) and ASTM standards for shock attenuation of playground surfacing were developed in an effort to provide a safe and attainable degree of impact attenuation (ASTM 1999). The primary goal of the surface shock attenuation standard is to prevent life threatening head injuries, although shock attenuating surfaces also appear to reduce the risk of other, non-fatal injuries. Fractures, lacerations and abrasions are more common, but the potential consequences of head injury are more severe. The shock attenuation specification is based on an impact test using an instrumented headform. The rigid headform is dropped on to the surface from a known height. The peak shock of impact (g_{max}) and a Head Injury Criterion (HIC) integral that considers both the magnitude and the duration of the impact shock are calculated, (see for example, Lockett 1985).

In the ASTM F1292 specification, the performance of a surface is rated in terms of its "critical height", defined as the drop height from which certain impact criteria are not exceeded. Specifically, the critical height is defined as the maximum height from which an instrumented headform yields g_{max}<200 and HIC<1000 upon impact at temperatures of 0, 70 and 120 °F. Similar performance specifications have been adopted in Canada, Europe, Australia and Asia. Typically, a playground installation is required to have a surface with critical fall height that exceeds the deck height (sometimes the rail height) of the play equipment.

The 200g and 1000 HIC limiting performance criteria are based on the thresholds at which the risk of a life-threatening head injury becomes non-zero. The mechanics of typical surfacing materials are such that surfaces fail the HIC criterion at a point when the g-max score is somewhat below the 200g limit. Consequently, HIC scores are frequently the limiting performance factor.

The limiting thresholds are based on studies of human cadavers, animals and biofidelic headforms. Strictly speaking, the thresholds do not apply to impact tests conducted with rigid headforms, such as the ones used ASTM F1292 test procedure and similar test methods used internationally. However, since a rigid headform produces g_{max} and HIC scores that are somewhat higher than those experienced by a real human head under the same impact conditions, the thresholds are conservative.

Shock Attenuating Surfaces

Many different materials have been used to attenuate the impact shock of a fall. The surfacing materials in current use are normally classified into one of two broad groups. Materials that are poured loosely on the ground below playground equipment are called “loose-fill’ surfacing materials. Surfaces that are manufactured on-site or installed as tiles and which form a continuous, immovable surfacing layer are generally referred to as “unitary” surfaces. The loose-fill class includes a variety of organic and inorganic materials whereas unitary systems are typically made of rubber and/or synthetic materials.

Loose-Fill Surfaces

Loose-fill surfaces consist of particulate materials such as wood chips, engineered wood fiber, sand, pea gravel, and plastic or rubber chips distributed underneath playground equipment at a depth that allows an impact to be absorbed through displacement of the particles or through compression of the air spaces between particles.

Although initially inexpensive to install, regular maintenance is essential for continued impact attenuation performance. Other drawbacks of loose fill surfaces include susceptibility to adverse weather conditions, the potential for injury from splintering, ingestion, or throwing of material, contamination (dirt, glass, animal feces and trash), and decomposition over time. Frequently, loose fill materials are not maintained at an adequate depth either because of inappropriate installation specifications, or because the surface is not well maintained. Finding a loose fill material that is both shock attenuating and wheelchair accessible can also be a challenge.

Table 3: Typical critical fall heights for dry, well-maintained loose fill surfaces.

Surface Depth	Gravel	Sand	Wood Chips	Wood Fiber	Shredded Rubber
Uncompressed Depth					
3”	3’	6’	4’	5’	4’
6”	5’	10’	8’	8’	12’
9”	5’	10’	10’	10’	12’
12”	6’		12’	12’	12’
Compressed Depth					
3”	4’	6’	4’	4’	4’
6”	4’	8’	6’	7’	12’
9”	5’	10’	8’	9’	12’
12”	6’	11’	12’	12’	12’

Table 3 shows approximate critical fall heights for different kinds of loose fill surfacing materials based on data from Mack et al (2000), the CPSC and International Playground Equipment Manufacturers Association (IPEMA). The ASTM test method does not currently take into account the possibility of freezing wet surfacing materials. Freezing decreases the impact attenuation of wood products, sand, gravel, and some kinds of rubber matting, making these surfaces unsafe for falls from higher than 5 feet under freezing conditions (Lewis et al 1993).

Ideally, loose fill surfaces should be maintained on a weekly basis. Maintenance programs are expensive, however. With many school districts and parks departments suffering tight budget constraints, the need for maintenance and safety inspections is frequently forgotten.

Unitary Surfaces

Unitary surfaces are continuous, monolithic surfaces, usually made of rubber composite materials. A typical installation has a cushioning layer of shredded or granular recycled rubber loosely bound with a polyurethane binder. A top layer of polyurethane bound EPDM rubber provides a durable, accessible wear course. Although expensive to install, unitary surfaces require minimal maintenance and typical installations easily meet accessibility criteria. They must be relatively thick (i.e. expensive) to meet critical fall height specifications in excess of eight feet.

In contrast to loose fill materials, the cost of a unitary surface installation is more heavily influenced by the cost of materials rather than labor costs. Cost cutting in specifications or during installation can result in inconsistent material depths, inconsistent performance and, in some case, exposed or thinly covered concrete footings.

On average, a trowelled-in-place rubber composite surface will add 1 foot to the surface's critical height for every half inch of material depth. While at ambient temperatures this is a conservative estimate, temperature extremes in either direction can reduce the shock attenuating performance.

Effect on Shock Attenuating Surfaces on Injury Risk

Studies of fall and injury patterns have found that the combination of fall height and surface shock attenuation influence the relative risk of injury.

Chalmers et al (1996) found that falls from heights greater than 5 feet were 4 times more likely to cause an injury than those from under 5 feet. Falls from 6'6" were 10.6 times more likely to result in an injury. Non impact-absorbing surfaces presented a 2.3 times greater risk of injury than impact-absorbing surfaces and inadequately maintained loose-fill surfaces created a 2.1 times greater injury risk.

Other published research also demonstrates the benefits of installing shock attenuating surfacing materials in playgrounds.

- "Keeping it Safe" 1998 USA (USPIRG) found that playgrounds not conforming to CPSC/ASTM guidelines had a 21 times greater risk of injury than conforming playgrounds.
- The relative risk of injury on rubberized surfaces is reported to be half that of bark dust and 5 lower than that of a concrete surface (Mott et al 1997).
- The rate of severe injury is reported to be six times greater on asphalt surfacing than on sand (Sosin et al 1993).
- The risk of serious head injury has been found to be 1.7 times greater on grass than on sand (Laforest et al 2000).
- Unsuitable surfaces increase the risk of severe head injury (Mack et al 2000). Depending on the fall height, between 79% and 100% of severe head injuries involve unsuitable surfaces. A fall from less than one foot onto an inappropriately hard surface can cause a severe head injury.

Despite the established reductions of injury risk when shock attenuating surfaces are installed in playgrounds, there are still a large number of facilities with inadequate surface installations. A 1998 study of 1353 U.S. playgrounds found that 75% (992) had an “impact absorbing” surface, however 72% of these (721) lacked enough depth of material to meet critical fall height criteria. 20% of the playgrounds studied had exposed concrete footings(MMWR 1999). Similarly, in 2002, 73% of American playgrounds are surfaced with loose fill material. Of these, only 15% are maintained at an adequate depth(U.S.PIRG 2002).

Surface Performance Optimization

The performance of a surface is determined by its material properties and by the properties of the impact to which it is

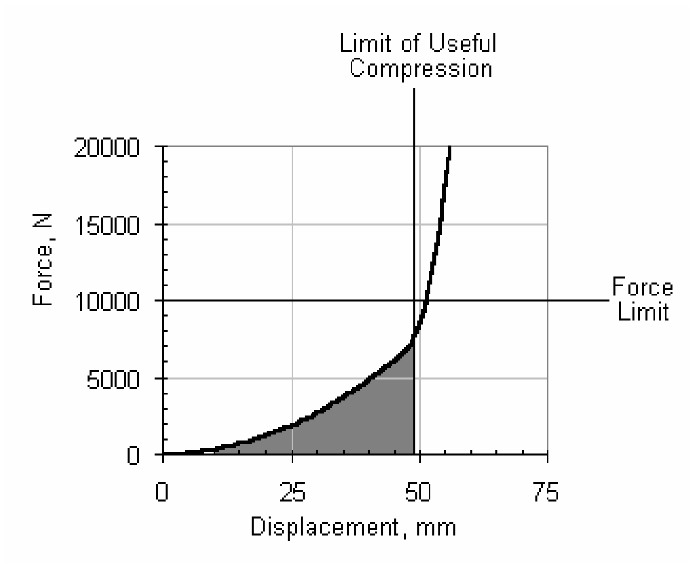

Fig.1: Force-displacement curve of a hypothetical surfacing material showing the specified force limit and the limit of useful compression. The shaded area is equivalent to the energy absorption capacity of the surface.

subjected. The impact of a falling mass may be characterized by the mass, geometry and velocity of the impacting mass. A spherical or head-shaped mass introduces some non-linearity into the impact dynamics that must be accounted for. The force-displacement curve of the material can be used as a basic way of characterizing the surfacing material. This curve (Figure 1) is a graph of the amount of force required to compress the surface, plotted against the amount the surface is compressed. The area under the curve is equal to the energy absorbed by the surface. Once the surface has been compressed by a significant portion of its thickness (typically 60-80%) progressively larger increments in force are required to compress it. At this point, the surface has reached the limit of useful compression and is said to have “bottomed out”.

The impact can be quantified by its “impact energy”:

$$\text{Impact Energy} = \tfrac{1}{2}\,\text{mass} * (\text{impact velocity})^2$$

In general, a playground surfacing material needs to absorb the impact of a fall without bottoming out and without exceeding the specified force or acceleration limit. In terms of the force-displacement curve, these requirements imply that the area under the curve, within the specified limits of compression and force, must be equal to or greater than the impact energy. For an F1292 impact test, the force limit is ~ 10,000 Newtons, equivalent to an acceleration of 200g. These constraints explain why surfaces designed for higher fall heights (e.g. higher impact energies) must be thicker than those intended for lower impact energies. Also, it should be apparent that for a given impact energy, there is a minimum thickness of surfacing that can attenuate the shock of a fall. This minimum must be such that the “energy box” determined by the force and compression limits is bigger than the impact energy.

Although useful models of surface impact mechanics are more complex than the example used here, Figure 1 does illustrate the basic principles that are used to engineer shock attenuating surfaces. To optimize surface performance, cushioning material properties are manipulated to change the shape and slope of the force-displacement curve. Surfacing materials that stiffen under load (i.e. the force displacement curve gets steeper as the surface is compressed) tend to produce higher peak accelerations during impact but lower HIC scores. Conversely, surfaces that soften when compressed (i.e. the force displacement curve gets less steep as the surface is compressed) have relatively low peak accelerations and higher HIC scores. Optimal cushioning properties are therefore dependant upon the criterion used to evaluate the severity of an impact. While peak acceleration (g_{max}) is sensitive to both the thickness and the non-linearity of the surface, HIC scores are most sensitive to the available compression in the surface (Shorten and Himmelsbach 2002)

In general, surfacing material properties that maximize the compression of the surface at the target impact energy have the best shock attenuation performance. Thinner surfaces are possible, but require the shape of the force-displacement curve to be manipulated (Shorten and Himmelsbach 2002).

Discussion and Conclusions

Injury statistics show clearly that falls to the surface are a significant cause of playground mortality and injury and that most fall-related deaths are associated with sever trauma to the head. Surfacing is not the only risk factor in a playground and “ideal” surfacing will not prevent all injuries but research has also shown that shock attenuating surfaces design to can mitigate the effects of head impact resulting from a fall and reduce the risk of injury. Social interventions, e.g. increased inspection and maintenance programs, signage promoting adult supervision and community clean-up efforts can also be effective in reducing injury rates (Laraque et al 1994;Sibert et al 1999;Roseveare et al 1999)
The relatively poor compliance with safety guidelines in public play facilities remains a cause for concern. Many installed playgrounds surfaces do not meet minimum shock attenuation requirements and are potentially hazardous. The cost of installing unitary surfaces and the cost of maintaining loose-fill surfaces continue to be a barrier to greater compliance.

A further concern is the disproportionately high rate of child deaths linked with home play equipment. The promotion of greater public awareness of the risks and greater availability of economical surfacing materials could be of value in this regard.

Education programs sponsored by government and non-profit agencies, changes in play equipment design and the availability of field-testing technology have all contributed to an improvement in playground safety in recent years. The challenge for the surfacing industry remains that of developing new surfacing systems that are affordable yet have superior shock attenuation performance.

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Acknowledgements

This review summarizes some of the information we have gathered over the course of several years of research into the mechanics and biomechanics of shock attenuating playground surfacing. We are grateful to a number of organizations which, during that time, have contributed resources to our work; particularly Seavey Inc. (Sausalito, CA), Continental Sports, Inc.(Chicago, Il), Skydex Cushioning Technologies, Inc. (Denver, CO) and NIKE, Inc. (Beaverton, OR).