Playground Equipment and Surfacing Manufacturer Hazard Analysis

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Understanding the risk of injuring a child beyond the most conservative threshold set by government regulations, standards or accepted by society is the best way to avoid future problems and costs that could bring a designer, manufacturer, supplier or installer to their knees. The performance of a Hazard Analysis can avoid problems down the road. The International Standards Organization (ISO) has published a number of documents Guides 50[1] and 51[2] and sport and recreational activities in ISO/TC 83, TR20183[3], to assist designers, manufacturers and consumer perform a Hazard Identification and Injury Prevention Plan. They assist the playground equipment and surfacing providers from the point of view of "if it can go wrong, it will go wrong" and it works well with prescriptive standards such as the ASTM F1487[4]. The existing ASTM F1487 is closely based on years of injury data and studies, the CPSC Handbook on Public Playground Safety[5], and the Comsis Report of 1989. The Comsis Report provides human factors for children and how they interact with the play environment.

The ISO Guide 50 speaks to "safe" environments for children and is closely tied to the Guide 51, which provides information on how to prevent injury in consumer products. Guide 51 provides readers with a flow chart on a Hazard Analysis[6]. The TR20183 takes these two ISO Guides and focuses them specifically to applications of sport, recreation and sports facilities, with the addition of injury definitions and thresholds. The scope says "*There shall be the utmost safe construction, production and maintenance covering a reasonable foreseeable misuse / intended use evaluated by the manufacturer. Any areas of risk have to be defined and precautions taken. Nevertheless the use of the equipment or activities with this equipment on sports or play grounds will create a residual risk related to the individual user. This has to be evaluated by a risk assessment and reduced to an acceptable or tolerable risk of performance*[7]." There cannot be a clearer mandate for the manufacturers to prevent injuries.

Playground environments have evolved in designs from the traditional post and platform to greater degree of climbing and structures that, depending on the child's perspective, can be used for multiple play activities. Creating play components that do not meet the traditional definitions in the ASTM F1487 or CPSC Handbook forces the manufacturer to consider all of the potential activities that children of all abilities and considering "reasonable foreseeable misuse" will do on the equipment. The scope of ISO TR20183 makes clear, it is the responsibility of the manufacture to prevent injuries that can be caused by or the result of using the equipment. Statistically falls from height are the highest mechanism of injury in playgrounds and the higher the free height of fall based on how children will use the equipment, not how the manufacturer would like them to used it, will result in the higher severity of injury. Manufactures must also consider designs from the point of view of the frequency of falls, considering individual children and groups that interact and bring

[1] (ISO, 2014)
[2] (ISO, 2012)
[3] (ISO, 2015)
[4] (ASTM, 2011)
[5] (CPSC, 1981)
[6] (ISO, 2012), page 4
[7] (ISO, 2015), page vi

horseplay, pushing and shoving to playground. Frequency of fall is based on design, while severity is based on distance of the fall.

Integral to any Hazard Analysis and the prevention of injury is a clear understanding of the severity of injury that is mandated for prevention by Federal and State authorities. The most stringent will be for those governed by the US Consumer Product Safety Improvement Act (CPSIA)[8], which requires the prevention of the "serious injury" (AIS>3). This class of injury includes fractures, lacerations, concussions and any injury the will require medical attention by a doctor or nurse. This level of injury is not necessarily consistent with the scope of ASTM F1487 (prevention of life-threatening (AIS>4) and debilitating (serious (AIS>3) with a legacy greater than a month). This discrepancy will place any manufacture that relies strictly on compliance to the ASTM standard at risk of facing an expensive recall. Manufacturers have the option of engineering the hazard out of the product, which may likely destroy the intended challenge and play value. The alternative is to use the Hazard Analysis and their professional experience and judgement to consider the potential height from which a child could fall to determine and require the surfacing performance requirements that results in the injury severity that does not exceed the limits allowed within the scope of the standards. It is therefore up to the owner/operator and the surfacing suppliers to step up and collaborate on actions that will address injury prevention.

Falls are statistically the highest cause of injury on traditional play structures and with the development of new structures demanding more intricate climbing and skill this risk increases. Falls, although blamed, are not the mechanism of the injury. It is the sudden impact with the surface that actually results in the injury. The structure manufacturer must consider the frequency of children falling and the height from which they will fall, but the surfacing supplier becomes a more than important component if the removal of hazards and injury prevention. Surfacing manufactures and specifically the surfacing installers, have the last look at the playground before the passive injury prevention system is deemed ready for use by children. Surfacing suppliers must understand all the mitigating factors affecting the performance of the surface they are installing beyond the point of sustaining a life-threatening injury. They all must consider the prevention of the serious injury related to the realistic fall heights based on the structures that have been installed and what children will foreseeably do with them.

Important to the prevention of injury is the long-term functionality of the surfacing system and its contributing factors to prevention of injury. Manufactures and installers must understand the factors detrimentally affecting the functionality of their products. Surfacing will be the most susceptible component to deterioration by being exposed to a harsh outdoor environment, constantly changing weather, UV exposure and the active traffic of hundreds of children. Critical to injury prevention is not just knowing the performance at the time of installation or as tested in a laboratory. All parties need to know the factors that will result in accelerating failure. Manufacturers and installers need to provide the owner/operator with warnings, signs of deterioration to look for and maintenance or replacement instructions that will sustain the surface performance and prevent the injury. Not providing this information, places the supplier of the failed components or surfacing system at risk of product recalls or law suits when the injury occurs.

Playgrounds – structures and surfacing – are complex environments that take a level of physics, chemistry and engineering then add creative design, challenge and the blending of structures with surfacing. With all of this complexity, we cannot have the simple expectation that owner/operators or children understand all injury prevention aspects, hazards or risks. As mentioned in ISO Guide 50 "children are not little adults[9]". A

[8] (USA, 2008), CPSIA
[9] (ISO, 2014), page v

clear presentation of the hazard analysis and injury mitigation coupled with detailed installation and maintenance instructions are the full responsibility of the structure and surfacing suppliers.

Owner/Operators are not free from obligation in the provision of the playspace. They should conduct their own risk assessment to ensure that the suppliers they have selected have provided a realistic Hazard Analysis for both the structures and surfacing. They must have clear instructions for both installation and maintenance. This will include the conditions under which failures to perform occur and how these conditions can be avoided or repaired. Inspections by competent persons to the performance requirements of ASTM F1487 and ASTM F1292 and essential. The ASTM F1487 inspection must be carried out by a CPSI using preferably probes that are rigid or made of metal. The ASTM F1292 inspection will require the test device and training of the person performing the test meeting all of the requirements of the F1292. The ASTM F1292 is where the owner/operator or the play structure supplier has the freedom to demand better performance than the absolute minimum[10]. The owner/operator is allowed to stipulate any "drop height[11]" for the testing of the surface and set the acceptable Gmax and HIC values to the level that will protect children from serious injury and themselves from crippling law suits. Inspections are critical at the time of purchase to ensure compliance to standards and contracts. It is equally important after initial installation and subsequently year after year to identify and correct failures before they result in an unacceptable injury.

Owner/Operators are the person closest to the installed playground to monitor the performance of the playground and particularly the occurrence of injuries. Any injuries should be reported to the manufactures of equipment and surfacing and the US CPSC. The manufacturer will be required by the CPSIA to provide details of the injury and cause to the CPSC. They will also need to evaluate if the cause of the injury is unique to the specific playground or systemic and related to the actual product that is the mechanism of the injury. If it is systemic, they are well advised to inform all customers with the same structure or surfacing systems of the problem and the way to prevent the injury.

Owners and their designer/consultants must be very careful they do not cross the line into the role of manufacturer/supplier, particularly when they are building playspaces that might be considered to be natural play or bring play elements to the playspace that are sourced from nature or the great outdoors. This will also extend to custom designed and built structures placed in the built environment that are used in unintended ways by children. Documents in support of natural play environments all provide cautions and injury prevention statements such as; "focusing on and controlling the most serious risks, that are not beneficial to the play activity or foreseeable by the user[12]"; "even if there are no binding design standards for nature play spaces, the standard of care will likely be identical for a natural play space as for manufactured play equipment because both are designed and intended for use by children[13]"; "in doing this, play provision aims to manage the level of risk so that children are not exposed to unacceptable risks of death or serious injury[14]"; a landscape that is safe, attractive, playful and social has a positive impact on how we feel.[15]"; Risks (situations in which a child can recognize and evaluate the challenge and decide on a course of action) have long been equated with hazards (a source of harm that is not obvious to the child, such that the potential injury is hidden)[16]". Where the owner or their professional consultant takes on any

[1010] (ASTM, 2009), page 5 (HSE, 2012)
[11] (ASTM, 2009), page 4
[12] (HSE, 2012), page 2
[13] (Moore, 2014), page 102
[14] (D. Ball, 2008), page 10
[15] (Grounds for Learning), page 7
[16] (Brussoni, 2014), page 2

role in the design or provision of the play activity, they will have to engage in the Hazard Analysis process, including all of the documentation that would be expected from a traditional manufacturer.

Understanding physics of falls and the user's impact with the surface are the most important to understanding the factors necessary to mitigation of impact injuries and therefore the following information of factors related to injury are important. The following provides medical and peer reviewed information that helps with the understanding of injury mechanisms and allows the performer of the Hazard Analysis in placing mitigating strategies in place to prevent the unacceptable injury. It quickly becomes apparent that not only does past injury data have a role, but understanding of potential injury based on new design really does become dominant.

Performing the Hazard Analysis that clearly mitigates injuries to a severity level below the acceptable threshold as identified in the scope of the standards is the only way a manufacturer, designer, supplier or installer can defend a complaint from the CPSC or brought in a law suit.

Hazard Analysis and Injury Prevention with Falls in Playgrounds

Children run the risk of playground injuries as a result of falls that are more severe than allowed for within the scopes of international playground standards such as; ASTM F1487, CSA-Z614 and EN1176. Falls are the leading cause of playground injuries, greater than all other causes combined and is one of the leading causes of death[17]. These standards suggest their purpose is for the prevention of life-threatening, fatal and debilitating injury. The ASTM F1292 Standard's focus is on the elimination of severe head injury through the management of impact attenuating surfaces within the playground use zones. These serious head injuries, up to recently, were thought to have been eliminated when the impact attenuation performance threshold for playground protective surfacing does not exceed 1000 HIC and/or 200 g. The stated performance value of 1000 HIC translates to a 16% risk of injury or an AIS >4[18] injury ad defined in the Abbreviated Injury Scale. An AIS injury >4 is defined as a severe, life-threatening, with survival probable. In addition a fall resulting in an impact force of 200 g translates to a 10% risk of skull fracture[19]. There has been a proposal to lower the HIC to 700 which will reduce the risk of an AIS>4 injury to less than 5%[20]. A 5% probability of injury occurrence is considered statistically insignificant. The lowering of the HIC threshold will also lower the Gmax for almost all playground surfaces. Lowering these values shall in effect decrease the severity of head injuries and also the most prominent of injuries in playgrounds, the long-bone injury.[21]

Discussion

Gmax and HIC have been used since the sixties and seventies in the automotive industry and actually this forms the basis for their use in playgrounds and other sports related injury prevention systems. The playground impact attenuation impact value of 200 g has been around in the playground community since 1981 and the HIC of 1000 since 1993. Fall related playground injuries have not been reduced since the first surfacing recommendations and standards were created. Falls have been increasing and becoming the

[17] (Tinsworth, 2001) page iii
[18] (Mertz, 1997) page 27
[19] (Mertz, 1997) page 26
[20] (Young, 2013) page 2
[21] (George Rutherford, 2004) page 13

biggest problem in playground. All major playground standards have addressed other playground impact injuries while their incidence of occurrence are far below that of falls in the use zone?

Of all playground injuries, falls, in general are the leading cause of Traumatic Brain Injury (TBI) in children within the ages of 2-14 accounting for 50.2%[22], while automobiles and traffic are at only 6.8%. In 2002 approximately 500,000 medically treated[23] playground injuries occurred in the United States with 230,000[24] requiring emergency room visits and a cost of treatment for playground injuries at just under $12,000,000,000[25]. Treatment for TBI has risen from 16,700 annually, 2001 to 2009[26], to more than 30,000 today and this is believed to be under reported by 10 times. It is imperative threshold values for playground surfacing systems be lowered to align with the scope of these swinging elements already being addressed by all international playground standards thereby reducing the probability for occurrence of the very injuries standards profess to address. A reduction in threshold performance would also provide a margin of error when the child makes an error in judgement of their ability to safely use the playground equipment.

Playground injuries have been increasing over the past 40 years ever since the National Recreation and Park Association (NRPA) (Besson, 1977)[27] was first approached by the US Consumer Product Safety Commission (CPSC) to prepare a guide for playground safety and injury reduction. Using the injury data available and the premise of "reasonably foreseeable misuse (Besson, 1977)[28]" the CPSC concluded that playground injuries needed to be addressed. In a 1978 memorandum on Public Playground Equipment, falls to the surface accounted for 59% of the 92,600 playground injuries in 1977 (Besson, 1977)[29], while impact with moving objects was 7%[30], such as swings and rotating equipment. "Over 90% of all reported injuries are attributable to one or more of three factors. It is either the way the equipment is used. It is the physical, developmental, cognitive or other limitations of the users. Or it is one or more design characteristics of the equipment." The Commission produced the first Handbook for Public Playground Safety in 1981, using what was considered "state of the art" technology[31] for the time. This information was based on sub-human primate and cadaver studies performed by the automotive industry and the military. Initially and without the benefit of modern imaging technology, they concluded that the threat of death from a head impact was 200g or a deceleration of the head at 200 times the acceleration due to gravity. In 1960 the Gmax value for risk of death was based on impact durations of less than 6 milliseconds[32]. The duration at 200g was revised in the 1970 Wayne State Tolerance Curve (WSTC) down to 2ms, meaning that anyone exposed to an impact value of 200g for less than 2ms[33] was considered as having a risk of death. Most impacts in the playground range from 2mc to 15ms.

[22] (TBI by External Cause, 2010)
[23] (George Rutherford, 2004) page 13
[24] (George Rutherford, 2004) page 13
[25] (George Rutherford, 2004) page 14
[26] (Julie Gilchrist, Nonfatal Truamatic Brain Injuries Related to Sports and Recreation Activities Among Persons Aged <=19 Years--- United States, 2001-2009 , 2011) page 7
[27] (Besson, 1977) page 3
[28] (Besson, 1977) page 125
[29] (Besson, 1977) page 5
[30] (Besson, 1977) page 5
[31] (Ratte, 1990) page 5.1-5
[32] (McHenry, 2004) page 4
[33] (McHenry, 2004) page 4

The CPSC Special Study: Injuries and Deaths Associated with Children's Playground Equipment, by Deborah Tinsworth et al. pointed out that 79% of injuries in public playgrounds and 81% of home injuries are the result of falls[34]. Of these 39% of the injuries were fractures, with 80% to the wrist, lower arm and elbow, while 15% of the injuries were to the head and face and were diagnosed as concussions, internal injuries and fractures[35]. Playground injuries in 1977, when emergency rooms were the primary facility for treatment, amounted to 93,000. The CPSC 1994 Special Report to Congress indicated there were 168,000 injuries[36]. In 1999 injuries to emergency rooms increased to 205,850[37]. The latter study was from a time when treatment facilities had expanded to include other medical treatment options and this fact accounts for the higher number. Injuries have more than quadrupled during a 20 year period from when the CPSC Handbook was first published. The ASTM F1292 was 8 years old as of 1999 and had been revised 4 times since its inception. At the time the F1487 was 6 years old. This increase in injuries, particularly falls, would indicate that the mechanisms to prevent injuries do not appear to be working and leave children open to severe and life-threatening. This severity level of injury is outside the scopes of all playground standards around the world. It must be remembered that the word "prevent" is not a synonyms for "expose".

US CPSC Report on Child Human Factors by the COMSIS Corporation

From the first publishing of the Handbook in 1981, the CPSC received negative input that the document did not reflect the reality of the playground. They engaged the COMSIS Corporation to study Human Factors Criteria for Playground Equipment Safety and evaluate some of there claims. The following comments are in the scoping and background of the report:

In developing safety recommendations, the difference between "challenge" and "risk" must be kept in mind. When children are able to anticipate the possible consequences of testing their skills on playground equipment, they are presented with a challenge which they can choose to undertake. However, if an activity has hazardous outcomes that are difficult for children to foresee, that activity poses a risk…. Risk, however, present the potential for serious injury as a consequence of failure. To minimize risk, unintended and unnecessary hazards should be eliminated.[38]

In an overview of the injury data the COMSIS Report noted;

- "It is important to distinguish between superficial injuries (e.g., contusions and lacerations) and serious injuries (e.g, head and limb fractures, concussion and internal head injuries)"[39]
- "Injury rates for the end of the 1980s was estimated by Nichols as 390/100,000, while King and Ball estimated that 500 children per 100,000 attend a hospital emergency room each year as a result of a playground equipment related injury."[40]
- "Falls to the surface were the predominant mode of injury in both age groups, accounting for 55% of injuries to younger children and 59% of injuries to older children."[41]

[34] (Tinsworth, 2001) page iii
[35] (Tinsworth, 2001) page ii
[36] (Brown, 1994) page 36
[37] (Tinsworth, 2001) page ii
[38] (Ratte, 1990) page 1-1
[39] (Ratte, 1990) page 3-4
[40] (Ratte, 1990) page 3-7
[41] (Ratte, 1990) page 3-7

- "Serious head injuries (including skull fracture, concussion, and internal head injury) accounted for a higher proportion of all slide-related injuries. Serious head injuries were prevalent among younger children on swings, slides and climbers. Younger children are probably at greater risk from impact with moving swings than older children, and more susceptible to head injury as a result of falls because they may not have sufficient motor coordination to their arms to break their fall and thereby protect their heads. (King and Ball 1989: Rutherford, 1979)"[42]
- Since the 1988 study, deaths from swing impact appear to have almost disappeared, but it did take the banning of heavy swings. Strangulation due to entanglement on ropes, shoestrings, cords, leashes, clothing strings, and similar items continues to be the most common scenario involved in fatal playground incidents.[43]

In relation to child development the COMSIS Report recognized the importance of play in the development of children with;

- "For young children, their play is their work…through play, children develop their intellectual, social, emotional, and physical (fine motor and gross motor) skills, as well as linguistic skills."[44]
- "Piaget's separation of cognitive development into three states is a convenient framework to use for organizational purposes; the sensorimotor stage is from birth to 2 years, the preoperational stage is 2 through 6 years, and the concrete operational stage is from 7 to 12 years."[45]

Under the issue of surfacing and the mechanisms and injury thresholds for various injuries, but particularly the head of the child were considered. This document noted the following;

- "In the current CPSC guideline, the impact performance criterion for surfaces under playground equipment is intended to minimize the risk of serious head injury resulting from head first falls."[46]
- "Acceleration can be defined as the time rate of change of velocity, which can either be positive or negative. (ASTM F355-86)"[47]
- "Head injury tolerance data for the head-first falls of children indicated that a conservative tolerance limit for head injury is 150-200g average acceleration for 3ms, or 200-250g peak g acceleration (Mohan et al, 1978)."[48]
- "The 1979 NEISS Special Study showed that severe head injuries represented only 7% of all injuries caused by falls to the surface, the potential severity of head injury relative to other body locations of injury warrants special precautions. There is more uncertainty in diagnosing brain injury than other types of severe injury (e.g. limb fracture), since functional brain damage is thought to occur at impact levels well below those producing skull fracture, coma, brain tissue lesions, or other visible signs of physical damage (King and Ball, 1989; Goldsmith and Ommaya, 1984). The mechanisms of brain and spinal cord damage are less well understood than the mechanism of skull fracture. A second consideration is that children tend to fall head first, and younger children in particular may not have sufficient motor coordination to use their arms to break their fall and thereby protect their

[42] (Ratte, 1990) page 3-8
[43] (Tinsworth, 2001) page 24
[44] (Ratte, 1990) page 4-1
[45] (Ratte, 1990) page 4-4
[46] (Ratte, 1990) page 5.1-4
[47] (Ratte, 1990) page 5.1-4
[48] (Ratte, 1990) page 5.1-5

heads. Thus, head injuries are more likely when children (12 years of age and under) than when adults fall, and the risk appears to be even greater for younger children. Moreover, the risk of functional brain damage is greater if the brain injury occurs during childhood, which involves periods of rapid brain development."[49]

- "The severity of injury resulting from a fall depend on the following physical parameters; fall height, shape and rigidity of the impact surface, and falling body, body orientation and body mass of the victim (Committee of Trauma Research, 1985; King and Ball, 1989; NBS, 1979a)"[50]
- "Skull fractures can result from direct impact, whereas brain injury can be due to a combination of impact and acceleration."[51]
- "In the absence of adequate models for the tolerance and structural failure limits of brain tissues, current criteria for head impact are based on threshold levels for skull fracture, which are assumed to be correlated with threshold levels for concussion (Goldsmith and Ommaya, 1984). Concussion is associated with 80% of all linear skull fractures; however, skull fracture can occur with substantial brain damage, and serious or lethal brain trauma can occur without noticeable skull damage or skull fracture (Goldsmith and Ommaya, 1984; King and Ball, 1989). Therefore skull fracture does not reliably indicate the presence or severity of brain injury (Sweeney, 1979a)."[52]
- "There is consensus in the literature reviewed, not only that tolerance levels for brain injury are below those for skull fracture, but also that functional damage to neural tissue can occur prior to evidence of structural tissue failure that results from shearing forces on neural tissue (Committee on Trauma Research, 1985; Goldsmith and Ommaya, 1984. For example, diffuse brain injuries, which are associated with widespread primary brain damage, generally show no signs of physical damage either to the skull or the brain, yet can lead to complete loss of memory, or to dysfunction in motor, cognitive and verbal skills (Collantes 1989)"[53]
- "Given that functional brain damage can occur at impact levels well below those produced by skull fracture or mechanical disruption or neural tissue, diagnosing brain injury can be difficult."[54]
- "There is consensus in the literature that apparently minor head injuries sustained by children may be associated with neuronal damage, and may result in persistent physical, mental, or behavioral changes, including sensory abnormalities, and increase risk of psychiatric disorders (Ball 1988; King and Ball 1989; Kraus, Fife, Cox, Ramstein and Conroy, 1986; Mohan et al., 1978)"[55]
- "Regardless of fall height, children tend to land on their heads after falling from a standing position and rotating during the fall onto their heads; adults tend to land foot or side first."[56]
- "Children tend to land head first when they fall and so are at greater risk of head injury due to falls than adults…. Impact tolerance values from adult data may not be conservative enough when they are used to predict the severity of head injuries sustained by children."[57]
- "The CPSC guidelines recommend that a surface tested in accordance with this method should not impart a peak acceleration of more than 200g to the instrumented headform. Three other models

[49] (Ratte, 1990) page 5.1-7
[50] (Ratte, 1990) page 5.1-7
[51] (Ratte, 1990) page 5.1-8
[52] (Ratte, 1990) page 5.1-8
[53] (Ratte, 1990) page 5.1-9
[54] (Ratte, 1990) page 5.1-10
[55] (Ratte, 1990) page 5.1-10
[56] (Ratte, 1990) page 5.1-11
[57] (Ratte, 1990) page 5.1-12

for predicting head injury severity are based on linear acceleration, but also take into account the duration of impact: the Wayne State Tolerance Curve (WTSC), the Severity Index (SI) and the Head Injury Criteria (HIC)"[58]

- "The AIS is a qualitative scale that assigns values from 0 to 6 to head injuries, ranging in severity from no injury (AIS =0) to maximum and currently untreatable injury (AIS=6). An AIS value of 2 corresponds to moderate, reversible injury and includes a simple skull fracture and mild concussion; this is the minimum AIS rating for skull fracture. Brain damage can be assigned AIS values between 3 and 6, depending on severity. An AIS value of 3 corresponds to [serious], but reversible damage; 4 dignifies a [severe], life-threatening injury that is potentially survivable; and 5 is reserved for critical injuries in which survival is uncertain."[59]
- "An SI value of 1000 is used to estimate the upper limit for survival from internal head injuries caused by frontal blows to the forehead. Since an SI of 1000 corresponds to the median SI value that distinguished between survivors and non-survivors in simulated accident studies, it is clear that serious head injury can be expected at lower values (King and Ball, 1989)."[60]
- "The Head Injury Criteria (HIC) is an alternate interpretation of the WSTC (King and Ball, 1989). The portion of the impact pulse covered by the HIC was intended to taking into account the rate of load application, which is thought to be critical in determining soft tissue injury (Committee on Trauma Research, 1985; Goldsmith and Ommaya, 1984. An HIC value of 1000 is taken as the concussion tolerance threshold and is currently used by the US Department of Transportation as the standard for evaluating head injury and testing safety systems (e.g. restraint systems) in the context of vehicular collisions."[61]
- "There is also the practical considerations that the peak g is easy to measure, as compared to the SI and HIC; not all laboratories have the requisite level of technical ability or quality control to measure SI or HIC reliably (King and Ball, 1989)"[62]
- "Mertz and Webber (1982, cited in King and Ball, 1989) estimated the percentage of the adult population expected to experience life-threatening brain injury (AIS level greater than or equal to 4) as a function of HIC (or SI for simple head impacts). They found that 56% and 16% of the adult population would be expected to experience such injuries at HIC values of 1500 and 1000."
- "First, for most playground surfaces tested, an SI of 1000 is thought to be roughly equivalent to peak values between 150 and 200 g."[63]
- "With regard to the 200 peak g criterion, King and Ball (1989) stated that it "is not a particularly conservative figure so far as child injury and playground design are concerned." In summarizing estimates of risk to children associated with peak g limits, they concluded that above 200g there is a grave risk of permanent brain injury resulting from a head-first fall, between 150 and 200 g there is moderate risk and below 50 g one can be fairly confident of no permanent brain injury."[64]

Once the COMSIS corporation reviewed the impact values and found them lacking, they moved on to the ability to test the surface system. They noted that in the 1980s there were various headforms to select from. They were all metal and offered varieties of mass and shape including the ANSI B and C and what has

[58] (Ratte, 1990) page 5.1-13
[59] (Ratte, 1990) page 5.1-14
[60] (Ratte, 1990) page 5.1-15
[61] (Ratte, 1990) page 5.1-15
[62] (Ratte, 1990) page 5.1-17
[63] (Ratte, 1990) page 5.1-20
[64] (Ratte, 1990) page 5.1-20

now become the accepted 4.6kg hemispherical headform used around the world since 1999. Other comments were:

- "Although the ANSI C metal headform was designed to simulate the human head in mass and geometry, the headform is rigid and so does not simulate the compressible tissue of the head (e.g. the scalp). As a result, the ANIS C headform and other rigid headforms (i.e. metal or wood) produce higher acceleration values and this provides more conservative estimates of head impact response, as compare to a resilient headform (King and Ball, 1989; NBS, 1979a). However, this effect of using a rigid headform is less pronounced in test of non-rigid surfaces than in tests of rigid surfaces."[65]
- "Specifying additional temperatures is important because in regions with extreme climates, very hot or cold temperatures (and low precipitation) tend to reduce the effectiveness of surfacing materials such as earth and grass (King and Ball, 1989)."[66]
- "Volume 1 of the current guidelines suggests maintaining a 6-inch depth of organic loose materials (e.g. pine bark, nuggets, shredded hardwood bark). However, there is a strong consensus in standards and in the literature that a more conservative depth is warranted."[67]
- "The peak g model does not take into account the effects of impact duration, angular acceleration, impact locations other that frontal head impact, and direction of impact other than the anterior-posterior direction associated with frontal head impact."[68]
- "The peak g model has not been correlated with the risk of structural or functional brain damage, particularly for children."[69]
- "The 200 peak g tolerance limit is based on linear skull fracture data, yet functional and structural brain damage can occur at impact levels well below those produced by skull fracture."[70]
- "The 200 peak g tolerance limit is based primarily on adult data, but there are important differences in the skull characteristics and head impact responses of children and adults."[71]

An important component of testing impact attenuation is choosing a height from which the headform is dropped that reflects the potential for fall height based on "reasonable foreseeable misuse" of the playground structures by children. The COMSIS comments analyzed fall height with:

- "The highest accessible part of the equipment should be determined in the following way. Since children can fall from a swing seat at its maximum attainable angle (90 degrees from vertical), the highest part of a swing structure is equivalent to the maximum height of its support structure. On slides and platforms that have a guardrail or protective barrier, the highest accessible part corresponds to the maximum height above ground of the guardrail or protective barrier, rather than the maximum height of the platform itself. This takes into account the possibility that children may gain access to the top of the guardrail or barrier. For example, a 60 inch-high platform with a 38 inch protective barrier requires protection from falls up to 98 inches. On upper body devices, such as horizontal ladders and overhead rings whose top support bars are climbable, the maximum height of the device is taken from the highest accessible part."[72]

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[65] (Ratte, 1990) page 5.1-22
[66] (Ratte, 1990) page 5.1-23
[67] (Ratte, 1990) page 5.1-27
[68] (Ratte, 1990) page 5.1-29
[69] (Ratte, 1990) page 5.1-29
[70] (Ratte, 1990) page 5.1-29
[71] (Ratte, 1990) page 5.1-29
[72] (Ratte, 1990) page 5.1-30

- “Further, there is some evidence that when young children do fall, they do not tend to break the fall with their hands and arms; therefore they are more likely to experience head first impacts than school-age children.”[73]

Once the impact measurement, test device, drop height and the results of the testing are known, it is necessary to communicate the performance of the surface associated with a particular play structure. The COMSIS Corporation recommended labelling with:

- “Manufactures of surfacing materials should supply the result of impact attenuation tests conducted by an independent lab in accordance with the ASTM draft standard for playground surface systems; they should also provide information on environmental conditions and other factors that affect the impact absorbing potential of the products, as stated above.”[74]
- “Because conformance with the 200 peak g criterion requires knowing the maximum height for which protection from falls is required, a durable label should be permanently affixed in a prominent location to all playground equipment with the following information; 1) all playground equipment requires impact absorbing protective surfacing; 2) this piece of equipment requires protection from falls from a height of x feet.”[75]

Reconstruction of a Playground Fatality resulting from a Fall

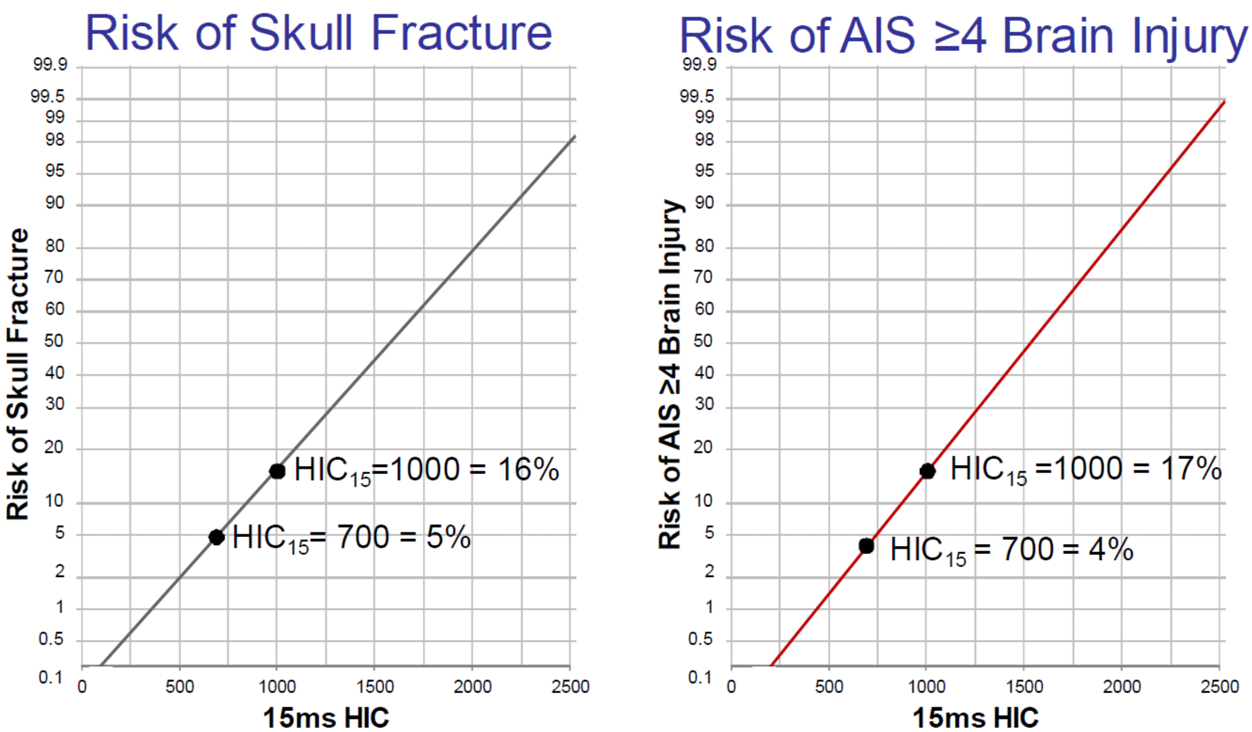
In the Chris Van Ee reconstruction of a child death from climbing over the barrier on a plastic home structure and falling to the surface it was found that the child had considerable damage to the brain and died 36 hours after the incident. Some of the important parts of the study are as follows:

- “*She had climbed the attached ladder to the top rail above the platform and was straddling the rail, with her feet 0.70 meters (28 inches) above the floor. She lost her balance and fell headfirst onto a 1-cm (⅜-inch) thick piece of plush carpet remnant covering the concrete floor.*”[76]
- “Results of the reconstruction are shown in Table 2. The differences between the two types of carpet were insignificant. The overall averages for HIC and peak linear acceleration were 335 and 125 g, respectively. The time window for maximizing the HIC calculation was quite short with an average of 3.7 ms.”[77]
- “Currently there is not a specific skull fracture threshold associated with the CRABI-18, but the experimental results of this study indicate that the tolerance for skull fracture for a 23 month old child is likely greater than the 50% threshold value of 82 g’s and 290 HIC associated with the CRABI-6 [16].”[78]
- “The results of this reconstruction are consistent with the current injury criteria based on both linear and angular acceleration. The CRABI-18 test device is an important tool in the assessment and evaluation of injury prevention and forensic investigation. This study further underscores the efficacy of this device.”[79]

[73] (Ratte, 1990) page 5.1-31
[74] (Ratte, 1990) page 5.1-32
[75] (Ratte, 1990) page 5.1-32
[76] (Ee, 2009) page 1
[77] (Ee, 2009) page 2
[78] (Ee, 2009) page 4
[79] (Ee, 2009) page 5

HIC and Head Injury Severity

The 2013 paper by Tyler Young on the prediction of mild traumatic brain injury provided:
"In 1997, Mertz developed an injury risk curve based on the Head Injury Criterion (HIC) which has been shown to accurately predict severe head injuries such as skull fractures"
"In order to more accurately predict injury, a 15ms timespan is used for the HIC15 to ensure the most severe acceleration interval is used."[80]



Mertz et al. developed injury risk curves to predict skull fracture and AIS>4 brain injuries based on HIC15[81]

"While the HIC15 has proven to be useful in mitigating severe head injuries, mild traumatic brain injuries, such as concussions, are not addressed. More recently, the biomechanics of mild traumatic brain injuries have been studied by analyzing the effects of linear and rotational acceleration on human brains"[82]
"It was determined that the maximum principal strain and peak coup pressure in the brain increases with linear acceleration in the direction of impact."[83]
"These risk curves are a valuable tool that can aid researchers in designing safer vehicles, protective equipment, and products that can minimize the amount injuries that occur during traumatic events"[84]

Gmax and Head Injury Severity

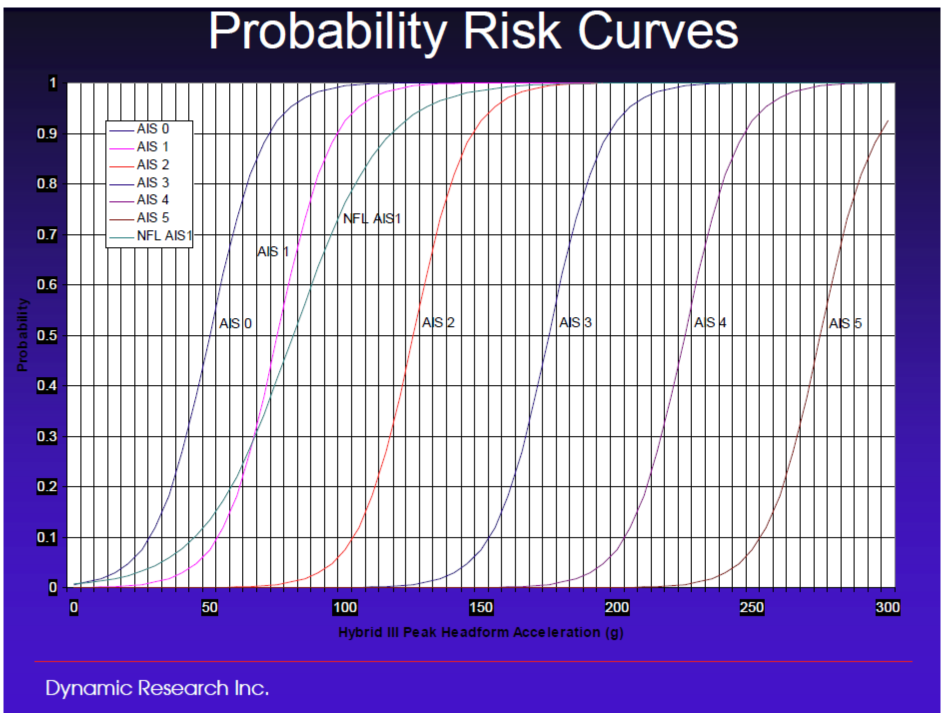
In 2005, Terry Smith, Ph.D., a member of the ASTM F08 head gear group delivered a presentation on *Linear Acceleration Probability Risk Curves*. The goal was to improve understanding of head injury and accelerations associated with those head injuries.

[80] (Young, 2013) page 2
[81] (Young, 2013) page 2
[82] (Young, 2013) page 2
[83] (Young, 2013) page 3
[84] (Young, 2013) page 6

“AIS Injury Severity”[85]

AIS Severity	Injury	Propose g range (Newman, 1989)
0	none	0-50g
1	Headache, dizziness	50-100g
2	Unconscious < 1hr	100-150g
3	Unconscious 1-6 hrs	150-200g
4	Unconscious 6-24 hrs	200-250g
5	Unconscious >24 hrs	250-300g
6	Dead	300g

The plot of AIS risk of injury related to the linear acceleration, including the NFL risk of concussion[86]



Frequency and Severity of Injury

The frequency of injury in playgrounds depends to a large extent on the challenges presented and the ability of a child to master them. With certain structures, failure to meet the challenge will result in a fall. When the fall occurs, the severity of the injury will range from none to death depending upon the surface upon which the body lands, how far it falls and how it lands. Julie Gilchrist, MD, from the US CDC gave a presentation to ASTM F08 at the Atlanta meeting in 2012. Some of her observations are:

[85] (Terry Smith, 2005) slide 11
[86] (Terry Smith, 2005) slide 14

"Definition of Concussion" is "a type of traumatic brain injury caused by a bump, blow or jolt to the head or body" that "changes the way the brain normally works" and is a "functional injury, not structural." "Young children and teens are at greater risk and take longer to heal."[87] The frequency of TBI for 0-4 years is 71/100,000 and 5-9 years 184/100,000 and 291/100,000 of the 10-14 age group[88]. TBI amongst children has constantly risen from 177/100,000 in 2002 to 298/100,000 in 2009, a more than 50% increase[89]. In the age groups of 0-4 and 5-9, TBI caused in playgrounds is either the first or second leading cause of injury.[90] Although TBI are increasing and can be devastating to the injured party and their families with long term consequences, fractures at 82,987 with 48,843 to the lower arm and wrist[91] suggests that impact is major mechanism of this type of injury as well.

Other CDC publications *TBI by External Cause* categorized falls, struck by/against, motor vehicle and traffic, assault, other and unknown in total and by age group. For the general population falls are 35.2%, while vehicular is 17.3%[92]. By comparison falls for 0-14 age group rise to 50.2%, while vehicular and traffic injuries are only 6.8%[93], confirming the observation of the COMSIS Report that children at this age are more prone to falling and fall to the head and upper body[94], leading to the conclusion that the activities children are involved with would benefit the greatest by improved impact attenuation values. Statistics show that the numbers of injuries treated both at the Emergency Room and other medical facilities are increasing rather than decreasing, again leading to the conclusion that the mechanisms for mitigation of injury currently in place for more than 30 years through standards and the CPSC Handbook (1000 HIC and 200 g) are inadequate.

The Ontario Injury Compass report on playground falls reported 78.6/100,000 for emergency room visits and 5.0/100,000[95] for hospitalization is interesting in that it separated the type of injury as to whether the injured party was hospitalized or treated and released. Concussions, although a serious injury, are generally diagnosed and sent home for rest and further observation by a family practitioner, while those requiring hospitalization are definitely of a severity needing round the clock monitoring and treatment. Similarly simple fractures and sprains can be diagnosed and treated with or without casting and subsequent follow-up. Since this data is exclusively related to falls in playgrounds, the injury mechanism can only be an interaction between the falling child and the surface.

Cost of Injury

Canada has had a playground performance standard, CSA Z614, since 1990. Due to North American trade there have been efforts to harmonize this standard with ASTM F1487. The primary differences have been since 2007 when the fall heights for structures was moved from the platform to the top of barriers and guardrails in Canada. Canada has a population of 35.16 million and GDP of US $1.827 trillion[96], while the United States has a population of 316.1 million and a GDP of US $16.80[97] trillion. Typically when comparing

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[87] (Julie Gilchrist, Epidemiology of TBI in Sports & on Playgrounds, 2012) slide 2
[88] (Julie Gilchrist, Epidemiology of TBI in Sports & on Playgrounds, 2012) slide 6
[89] (Julie Gilchrist, Epidemiology of TBI in Sports & on Playgrounds, 2012) slide 19
[90] (Julie Gilchrist, Epidemiology of TBI in Sports & on Playgrounds, 2012) slide 13
[91] (Julie Gilchrist, Epidemiology of TBI in Sports & on Playgrounds, 2012) slide 17
[92] (TBI by External Cause, 2010) page 3
[93] (TBI by External Cause, 2010) page 4
[94] (Ratte, 1990) page 5.1-11
[95] (SmartRisk, Ontario Injury Compass - Playground Falls, 2007) page 1
[96] (Canada, 2015)
[97] (United States of America, 2015)

statistics between the two countries they are multiplied or divided by 10 depending upon the source of the statistics. In relation to health care, Canada has a universal health care system where many costs associated with treatment and rehabilitation are paid for by the government and therefore a cost to the taxpayer, whereas the United States has a user pay system, where costs are paid by insurance or personally.

The SmartRisk data for 2004 is based on the NARCS database system and primarily relates to treatment received from hospitals and other sources, but the actual total number of injuries treated for a particular cause is not captured. Since Canada covers a vast geographic area and playground injuries such as concussions are under-reported or can be treated by other medical practitioners and facilities, it is likely that a significant number of injuries are unaccounted for. In any event, the data shows that falls for all ages are the highest in cost and number in relation to all other injuries when considering both direct and indirect costs. This study did not look at all playground injuries, but only those that were the result of a fall on the playground. Playgrounds falls accounted for 1,662 that required hospitalizations, and 21,158 that were treated and released, with 551 having partial and 37 having permanent disabilities[98]. These are outside the scope of international playground standards requiring the prevention of the debilitating injury. The costs were $106 million in direct costs, $79 million in indirect cost for a total of $185 million dollars[99]. Using the simple multiplier of 10, the direct cost would be $1.06 billion dollars for the cost in the United States which roughly corresponds to the $1.2 billion for 1995[100] reported by the CDC however not even close to the actual costs reported by the CPSC in 2004 to Congress for the year 2002 of $11.8 billion[101]. This would indicate that the cost of injuries in playgrounds is significant to extreme in both number and dollars. Therefore methods to mitigate injury justify the cost of improvement, particularly in relation to surfacing given the low cost alternatives such as woodchips and Engineered Wood Fiber (EWF).

Lower Incidence of other Injuries

When looking at lowering impact attenuation properties for a particular surfacing system based on the calculation of HIC, there is the added benefit that all measures of impact attenuation since the calculation for both HIC and SI as dependent on g. This has the benefit, in terms of all fall related playground injury, of reducing other injuries severity such as long-bone injury and severity of concussions.

Mary Clyde Pierce, et al. evaluated bone fractures in children pointing out;"fracture morphology reflects; (1) the forces and resultant stress generated by the specific mechanism and (2) the ability of the bone (and its surrounding tissues) to resist these forces."[102] "There are three pure forms of force: compression, tension, and shear. A *compressive force* is a pressing or squeezing force that is directed *axially* through the body or region (Hall, 1999, p. 73). *Tension* is a force that is also directed axially but results in stretching or pulling, rather than compression. *Shear* force tends to cause one part of the body to slide with respect to an adjacent part (Evans, 1974; Hall, 1999, p. 73)."[103]

"Extrinsic factors to the body include magnitude and direction of force, rate of loading, and area over which the force is distributed. Environmental factors such as surface type, height of fall, and initial velocity (standing, walking, running, propelled *. . .)* influence loading. Magnitude of load is also affected by the

[98] (SmartRisk, The Economic Burden of Injury in Canada, 2009) page 18
[99] (SmartRisk, The Economic Burden of Injury in Canada, 2009) page 21
[100] (Playground Injuries: Fact Sheet, 2015)
[101] (George Rutherford, 2004) page 13
[102] (Pierce, 2004) page 506
[103] (Pierce, 2004) page 507

degree to which the impact surface can absorb and dissipate energy. Softer surfaces result in less energy available for injury while harder surfaces are more efficient in transmitting the energy to the body."[104]

"Mechanisms of injury generate specific forces called loads that have the potential to cause structural damage. If the mechanism results in forces that exceed the injury threshold of a long bone, then a fracture is generated. The fracture morphology is a direct reflection of the degree and direction of the forces and the ability of the tissue to resist those forces. Mechanisms that generate greater amounts of energy with greater magnitudes of force may result in a completed fracture with the fracture type depending on the resultant combination of forces and moments."[105]

The University of British Columbia, Pediatric Fractures paper reviews the causes of fractures in children with the following:

"The anatomy and biomechanics of pediatric bone differ from that of adult bone, leading to unique pediatric fracture patterns, healing mechanisms, and management. In comparison to adult bone, pediatric bone is significantly less dense, more porous and penetrated throughout by capillary channels. Pediatric bone has a lower modulus of elasticity, lower bending strength, and lower mineral content. The low bending strength induces more strain in pediatric bone than for the same stress on adult bone and the low modulus of elasticity allows for greater energy absorption before failure. The increased porosity of pediatric bone prevents propagation of fractures, thereby decreasing the incidence of comminuted fractures."[106]

"The mechanisms of fracture change as children age. Younger children are more likely to sustain a fracture while playing and falling on an outstretched arm."[107]

"Also, because a child's ligaments are stronger than those of an adult, forces which would tend to cause a sprain in an older individual will be transmitted to the bone and cause a fracture in a child."[108]

These would indicate that magnitude of impact forces are key factors in fractures and severity of fractures. Lower impact values for g and HIC will result in lower severity of long bone injury from falls.

In the Montreal study of actual playground injuries for 1995, prior to the F1292-99 which formalized the free-fall test procedure, and before recommended and mandated periodic field testing was adopted by the CSA Z614-98, reviewed 110 actual injuries in relation to impact attenuation and actual severity of injury. The result showed;

"*Conclusions* — This study confirms the relationships between risk of injury, surface resilience, and height of equipment, as well as between type of material and severity of injury. Our data suggest that acceptable limits for surface resilience be set at less than 200 g, and perhaps even less than 150 g, and not exceed 2 m for equipment height."[109]

"The results show that the composition of inspected surfaces do not appear to be associated with the risk of injury, whereas the g-max and height of the equipment are."[110]

"Surfaces exceeding 200 g were three times more likely to be involved in an injury than those lower than 150."[111]

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[104] (Pierce, 2004) page 508
[105] (Pierce, 2004) page 520
[106] (Budd, 2015) Introduction
[107] (Budd, 2015) Pediatric fracture patterns
[108] (Budd, 2015) Pediatric fracture patterns
[109] (Laforest, 2001) page 35
[110] (Laforest, 2001) page 37
[111] (Laforest, 2001) page 37

"the findings suggest that the g-max is a good predictor of fall injuries independent of the severity of the injury. The risk of injury was 1.8 times greater in the 150–199 g category compared with the reference category (<150 g)."[112]
"This research strongly suggests that improving surfaces will help reduce the severity of injuries."[113]
"In fact, 70% of all injuries occurred on play equipment higher than 2 m, whereas only 42% of all playground equipment exceeded this height."[114]
"In conclusion, these data provide evidence that g-max is associated with the risk of injury and place into question the 200 g acceptable limit."[115]

Use of Lower Impact Values Standards to Prevent and Lower the Severity of Injury

Starting with Cynthia Illingworth, et al. back in the mid-1970s there has been a concern with the provision of impact attenuation for moving elements and surfacing, in particular swings[116]. This was the inspiration for the impact attenuating swing seat developed, patented and sold by Sutcliffe Play in England with a 50g value[117]. Other standards such as the CSA Z614 and ASTM F1487 required that swing seats be for single users to reduce the mass. Generally this was achieved through descriptive language such as recommending that they not be heavy or should be made of energy absorbing materials or requiring swing seats not accommodate more than one user. The advent of the need for greater inclusion in play gave rise to the multi-user swing that increased mass and therefore raised fears for a new potential for hazard. The larger swinging mass raised concerns for a return to the steel animal swings that were banned by the US CPSC in 1995 under release # 95-059 because these swings caused serious head injuries for 42 children and also 2 deaths[118]. This caused the removal of approximately 10,000 swings and a significant cost to the owners and manufacturers, yet there was no outcry asking for a cost benefit on the removal. This was just accepted and everyone moved on.

Based on the Sutcliffe commercial effort and that of the British Standards Institute (BSI) and DIN, the need for a formal test for the impact attenuation of swing seats was developed as a component of the EN1176 part 2 Standard. This effectively utilizes the same headform (4.6kg) that is used in the testing of playground surfacing reconfigured to a sphere and suspending it in front of the impacting swing seat. The EN1176-2 set the limit for "swing seats and vertical tyre seats" as not to exceed 50 g, while for "swing seats and platforms for several users" having a diameter greater than 900mm shall not have an impact value greater than 120 g[119]. The ASTM F15.29 sub-committee for playgrounds, which is responsible for the entire playground including swings and playground surfacing through referencing compliance with ASTM F1292, made the decision to add a swing impact test to the ASTM F1487-11 using the same device and procedure as in the EN1176-2. For all swing seats the Gmax shall be not exceed 100 and the HIC shall not exceed 500[120]. Lastly

[112] (Laforest, 2001) page 39
[113] (Laforest, 2001) page 39
[114] (Laforest, 2001) page 39
[115] (Laforest, 2001) page 39
[116] (Sutcliffe Play; The story of the swing, 2015) page 4
[117] (Sutcliffe Play; The story of the swing, 2015) page 4
[118] (CPSC and Manufacturers Alert Playgrounds to Remove Animal Swings, 1995)
[119] (Playground equipment and surfacing - Part 2: Additional specific safety requirements and test methods for swings, 2008) section 4.6

the CSA technical committee for Playspaces adopted the test method and values from the F1487 in the 2014 revision to Z614-14[121].

The swing impact tests have been a beacon of protection for children around the world, but the question might be: what is the frequency of injury this change is focused on? Tinsworth noted that "about 80% of the injuries associated with swings involved falls[122]" and "about 3% of the injuries involved impact with moving equipment, such as swings"[123].

It is difficult to understand that swing impact has been such a dominant topic during the mid-1990s and into the new century when Tinsworth noted that "since the 1988 study, deaths from swing impacts appear to have almost disappeared."

Other changes where standards have modified the impact attenuation properties of playground surfacing is seen in the CSA Z614-07. This does not change the Gmax or HIC, but raises the fall height that is used as the minimum height for measuring critical height. While every standard in the world sets the fall height for a play structures with an elevated platform at the height of the platform, the Z614 provides:

"On elevated platforms where guardrails or protective barriers are required, the fall height shall be measured from the protective surfacing to 725 mm (28.54 in) above the elevated platform when intended for children 18 months to 5 years old and 950 mm (37.40 in) above the elevated platform when intended for children 5 to 12 years old."[124]

"The fall height of an elevated platform that is totally enclosed by protective barriers that meet the roof shall be the height of the elevated platform."[125]

"The fall height for any slide with a platform elevated more than 300 mm (11.81 in.) above the ground and where guardrails or protective barriers are required shall be measured from the protective surfacing to 725 mm (28.54 in.) above the elevated platform when intended for children 18 months to 5 years old and 950 mm (37.40 in) above the elevated platform when intended for children 5 to 12 years old and apply to the entire protective surfacing zone associated with the slide."[126]

This change is in line with the recommendation for fall height made in the COMSIS report. Additionally, the above change the CSA Z614 does not have a limit to fall height as the European and Australian Standards do. Coupling no limit to fall height and the "tops of barriers" minimum requirement, there is the opportunity to demonstrate that the change has not been an economic disaster. As it turns out the timing of the change in 2007 was not the best with the onset of the recession of 2008 just around the corner. However the perfect storm did not happen, there was not a downturn in playground installations and very little was said of the change.

Summary

[120] (Standard Consumer Safety Performance Specification for Playground Equipment for Public Use, 2011) section 8.6.4.2
[121] (CSA Z614-14, 2014) section 15.6.4.2
[122] (Tinsworth, 2001) page 11
[123] (Tinsworth, 2001) page 12
[124] (CSA Z614-07, 2007) section 15.16.1
[125] (CSA Z614-07, 2007) section 15.16.2
[126] (CSA Z614-14, 2014) section 15.16.3

Effectively the COMSIS report's information published in 1990 lead's to the following conclusions;

1. Falls to the surface were the highest proportion of injuries in the 1980s, with a rate of 390/100,000 in the US and 500/100,000 in Great Britain.
2. Children, younger ones particularly, do not have sufficient skill to break their fall with their arms
3. 150-200g for 3m/s was a conservative estimate for tolerance to head injury
4. 7% of head injuries at AIS >4 and head injuries as compared to injuries to other parts of the body need special consideration.
5. More uncertainty in diagnosing brain injury than other severe injuries, since brain damage can occur well below the impact values for skull fracture
6. Risk of functional brain damage is greater if the brain injury occurs during childhood, which involves a period of rapid brain development
7. Skull fractures can result from direct impact, whereas brain injury can be due to a combination of impact and acceleration
8. Serious or lethal brain trauma can occur without noticeable skull damage or skull fracture
9. Skull fracture does not reliably indicate the presence or severity of brain injury
10. Diffuse brain injuries, which are associated with widespread primary brain damage, generally show no signs of physical damage either to the skull or the brain, yet can lead to complete loss of memory, or to dysfunction in motor, cognitive and verbal skills
11. An AIS value of 3 corresponds to serious, but reversible damage; 4 dignifies a severe, life-threatening injury that is potentially survivable; and 5 is reserved for critical injuries in which survival is uncertain
12. Since an SI of 1000 corresponds to the median SI value that distinguished between survivors and non-survivors in simulated accident studies, it is clear that serious head injury can be expected at lower values
13. The portion of the impact pulse covered by the HIC was intended to taking into account the rate of load application, which is thought to be critical in determining soft tissue injury
14. Mertz and Webber (1982, cited in King and Ball, 1989) found that 56% and 16% of the adult population would be expected to experience such injuries at HIC values of 1500 and 1000.
15. King and Ball, 1989,in summarizing estimates of risk to children associated with peak g limits, they concluded that above 200g there is a grave risk of permanent brain injury resulting from a head-first fall, between 150 and 200 g there is moderate risk and below 50 g one can be fairly confident of no permanent brain injury.
16. The 200 peak g tolerance limit is based on linear skull fracture data, yet functional and structural brain damage can occur at impact levels well below those produced by skull fracture.
17. Manufactures of playground equipment must establish the highest accessible part of the equipment should be determined using reasonable foreseeable misuse.
18. On slides and platforms that have a guardrail or protective barrier, the highest accessible part corresponds to the maximum height above ground of the guardrail or protective barrier, rather than the maximum height of the platform itself, as adopted in the CSA Z614-07.
19. When young children do fall, they do not tend to break the fall, therefore they are more likely to experience head first impacts than school-age children.
20. Manufactures of surfacing materials must supply the result of impact attenuation tests
21. A durable label should be permanently affixed in a prominent location to all playground equipment with the following information; 1) all playground equipment requires impact absorbing protective surfacing; 2) this piece of equipment requires protection from falls from a height of x feet.

The reconstruction of the fatal play apparatus injury to a 23 month old child validated the automotive thresholds and reasonable foreseeable misuse;

1. The child fell and impacted her head with a Gmax of 125 and HIC of 335. This shows that the NHTSA threshold of 390 HIC for the baby is potential conservative and the 570 HIC being close to or beyond that for the 3 year child at 570 HIC.
2. The child at 23 months was able to not only climb onto the play apparatus to the intended platform, but also able to climb to the top of the barrier over which she fell.

The review of head injury predictors and models by Young in 2013 indicates;

1. An HIC of 700 is a 5% risk of skull fracture and 4% risk of a brain injury at AIS>4, while an HIC of 1000 is a 16% risk of skull fracture and 17% risk of AIS>4.
2. Increasing linear acceleration will also increase maximum principal strain and peak coup pressure.
3. The most severe portion of the HIC is restricted to 15ms or less, which is the range of playground impacts that are generally in the 3-9ms and therefore significantly more severe.

The presentation on risk of head injury based on linear acceleration by Terry Smith indicates anything over 100g is an injury no one should experience. The threshold for playground surfacing at 200 g allows significant injuries by linear acceleration. Any lowering of HIC from 1000 will result in a lowering of linear acceleration experienced by the child in a fall.

- 100-150g = unconscious for <1 hour
- 200-250g = unconscious for 6-24 hours
- 50-100g = NFL study risk of concussion

Julie Gilchrist, MD presentation on the severity of TBI in children and made the ASTM group aware of the work and information available from the US CDC;

- Challenge is essential to play value, physical, social and mental development of the child
- Debilitating injury through TBI must not extinguish the benefits of play
- High injury frequency does mean high injury severity if injury mitigation is in place
- Frequency of TBI in children is increasing
- For children TBI is the leading cause of injury for the 0-9 years group
- Falls are the mechanism for TBI in 50.2% of children 0-14, while vehicular and traffic is only 6.8%
- Children are more likely than adults to fall onto their heads and upper bodies

The Ontario Injury Compass looked at both the frequency and severity of injury sustained through falls in playgrounds;

- Concussions, although always serious and requiring treatment, do not always require hospitalization and may be discharged home from the ER and subject to future medical follow-up.
- Rate of injury from falls in playgrounds is 78.5/100,000 for treatment and release and 5/100,000 for hospitalizations.
- Fractures, primarily to the upper limbs, are the highest frequency for both treatment and release and hospitalization, while head in injuries are number two.

Any change that may have a cost associated with the change demands an understanding of the cost of what is being prevented. The best detail cost in relation to the falls in playgrounds comes from the SmartRisk in Canada for data in 2004.

- Canada is 1/10th the size of the US for economic output and population

- Annually in Canada, falls in playground account for 1662 hospitalizations, 21,158 Emergency Room treatment and release, with 551 partial disabilities and 37 permanent disabilities
- Falls in playgrounds account for $106,000,000.00 direct costs, $79,000,000.00 for indirect costs, giving a total of $185,000,000.00
- Annual cost of injury in the US in 1995 was $1,200,000,000.00
- Annual cost for playground injury in the US in 2002 was $11.8 billion

Lowering the HIC for playgrounds will have a positive outcome for the reduction of other injuries that have an impact component included in the mechanism of injury. The evaluation of Pierce et al. of long bone injuries in better understanding the violence of child abuse helps in understanding the mechanism of long bone fracture in children. The University of British Columbia pointed out some of the differences in bone structure for children and adults, while Laforest reviewed the severity of injury related to impact value.

- Fractures are caused by - the forces and resultant stress generated by the specific mechanism
- the ability of the bone (and surrounding tissue) to resist the forces
- Pure forces are; compression, tensions and shear
- Compression force is a pressing or squeezing force that is directed axially through the body or region
- Extrinsic factors to the body include magnitude and direction of the force, rate of loading and area over which the force is distributed.
- Surface impact attenuation performance, height of fall and initial velocity influence the loading
- Forces that exceed the injury threshold of the long bone, generate a fracture
- Younger children are more likely to sustain a fracture while playing and falling on an outstretched arm.
- Head injuries and fractures increase 1.8 times for surfaces between 150-199 g vs <150 g

Since 1975 there have been efforts in products and standards to mitigate the severity of injury sustained during impact on the playground. There are a number of standards that have adopted values lower than the proposed 700 HIC for surfacing.

En1177-2 requires – swing seats under 900mm in diameter to impart <50g
- swing seats over 900mm in diameter to impart <120g

ASTM F1487-11 requires all swing seats are to have the Gmax not exceed 100 and HIC not exceed 500
CSA Z614-14 requires all swing seats are to have the Gmax not exceed 100 and HIC not exceed 500
CSA Z614-07 to current revision requires the fall height of top of barrier and guardrail increasing height by 725mm (28.5”) or 950mm (37.4”) and therefore the velocity of the test device on impact, effectively lowering the HIC as compared to other standards having the platform as the fall height.

Answers to questions posed by those against lowering the surfacing performance thresholds

There have been some who have posed questions that need answering. Although the answers should by now be evident, there may need some specifics

What consideration is given to the likelihood that improved safety measures give children a greater sense of security, perhaps falsely, such that they take greater risks?
This is obvious from, Peirce, Ball, King, the COMSIS report, Laforest and others that lowering the impact value associated with a fall will result in a less severe injury and this will include head, upper body and long-bones.

Could a reduction in HIC change other injury mechanisms, such as those involving long bone fractures? What is the clinical evidence?
Again Peirce, Laforest and the University of British Columbia make it clear that long-bones fracture as a result of force and loading. Through the lowering of the impact value of the protective surface, the force and loading are reduced.

What would be the financial cost, given that there would be pressure to change playground surfaces already in place?
The cost of playground injuries in Canada in 2004 were $185,000,000 and for the United States in 1995 were $1.2 billion and in 2002 were $11.8 billion. It is not the cost of installing better surfacing or maintaining surfacing once it is in place that matters, it is the savings. A 5% saving on the 2002 cost would be $590,000,000 and a 1% saving would be $118,000,000. Enough said.

What would be the effectiveness of any such change?
Since most studies by the CPSC and the COMSIS corporation show that children are not consciously choosing to fall and falls are generally the result of "reasonable foreseeable use" or children testing their limits and just being children and taking risks that they understand, the frequency of falling will remain, but the severity of injury will be reduced through the removal of the hazardous situation of a non-attenuating surface. Obviously the effectiveness of impact attenuation is the height from which a child falls. Canada and the United States to not set upper limits for fall height and therefore challenging play structures will have a realistic fall height. The EN however allows for no impact attenuating surfacing for stationary equipment with <2' (600mm) above the ground for equipment with no forced motion, but ignore children pushing children and do require surfaces to be tested above 10' (3000mm) leading one to believe the changing impact attenuation has limitations for the countries using the EN1176 and En1177 standard.

What would be the cost to children's ability to access play space if funds were diverted from play provision to safety measures?
The opportunity for children to play would be enhanced, particularly if the savings to the injury treatment and rehabilitation side of the health function shows a savings, there is a good argument that the savings should be spent on increased play opportunities and playgrounds to take advantage of all of the advantages of play, including the potential for a reduction in childhood obesity.

Is the evidence directly relevant to children's playgrounds, and not taken from unrelated industry areas?
The impact values have been taken from the automotive industry and this is where the WSTC, SI and HIC have been developed and validated for measurement of impact values. Irrespective of the industry that funded the research and validation of the testing, the human body is the human body, acceleration is acceleration, and impact is impact. Alternatively we do have the reconstruction of the death that resulted from a fall from a play structure and the extensive child abuse information related to damage to the body. It is hoped that child's play on the playground is not the equivalent of child abuse, but some of the outcomes are abusive to the child.

Conclusion

For anyone preforming a hazard analysis in relation to playground equipment or surfacing falls to the surface have figure largely in the potential of an injury. Should that injury exceed threshold acceptable to government agencies, the manufacturer/supplier of either the structure that allowed the fall or the surfacing upon which the child landed could be the target of a Federal Government recall. The option for supplier literature for play structure is the lowering of the HIC value from 1000 to 700 and has obvious benefits and no downside. By applying a hazard based approach to not just standards development but to a designer's risk /hazard assessment one can eliminate or mitigate the potential hazard and allow for more fun challenging play and swinging experiences that could not have occurred with the 1970-1990 approach to eliminate only mass and hard surfaces for seats.

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