Impact Attenuation Values and Prevention of Head Injuries in Children's Playgrounds

Do Children Deserve the Same or Better Protection than in an Automobile Crash

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Abstract

There are more than 225,000 playground related injuries per year in the United States that result in an emergency room visit, and over 16,000 are traumatic brain injuries (TBI) and approximately 350 of those with TBI are admitted to hospital. It is suggested that TBI, especially in children is underreported by as much as 10 fold. A concussion for a child may have long-term debilitating effects and a second concussion prior to the complete recovery from the first could be life altering.

Cadaver, large animal and subhuman primate studies were initially used by the military and automotive safety engineers to provide initial impact prevention thresholds related to maximum acceleration. Initial studies resulted in the Wayne State Tolerance Curve (WSTC), leading to the Severity Index (SI) and Head Injury Criteria (HIC) during the 1960s and 1970s. These were used to establish values exceeding of 200 g's and 1000 HIC_{max} as being a risk to life. These values were being recommended by the Consumer Product Safety Commission and later became the impact attenuation thresholds of ASTM F1292 in the early 1990s.

During the 1990's, developments in automotive safety continued to improve the performance measures, injury consequences and impact attenuation values for the protection of vehicular occupants from risk of injury with an abbreviated injury score (AIS) >4. In 2000 new threshold values were set by the National Highway Traffic Safety Administration (NHTSA) for HIC_{15} at <700 for all crash test dummies 6 years and older and HIC_{15} <570 for the 3 year old crash test dummy. This is a model for the threshold of a life-threatening head injury for the relevant age group.

During the first decade of this century, concussions in sports, both amateur and professional gained prevalence. Through injury studies and media attention, the issue has achieved a raised profile. Studies of twenty-five concussed NFL players through reconstruction of the circumstances of the injury and ongoing studies using the Symbex Head Impact Telemetry System (HIT system) would suggest that concussions occur in professional, college and high school athletes in a range from 98 to 117 g's.

Based on these studies, it would suggest the current thresholds for ASTM F1292 and the recommendations of the Consumer Product Safety Commission for impact attenuation values for children's playground surfaces should get another look by injury prevention specialists and advocates. The playground industry is still operating in the 1970s to 1980s with threshold values of Gmax not exceeding 200 and HIC_{max} not exceeding 1000 for the determination of critical height or establishing the limited below which a serious injury is not likely to occur. These values do not recognize advances in research on injury prevention. Today there is credible evidence that these standards should move into the new century with thresholds substantiated by current research and injury data.

There are a number of factors that have come to light in relation to the ASTM F1292 and CPSC Public Playground Safety Handbook. The primary concern is the consideration of the Gmax and HIC values that are to become the threshold for compliance to the standard. Although most of the impact intervals related to playground surfaces are generally less than 10ms as in the automotive studies, there are some surfaces designed for very low Gmax and HIC at above 10' (3m) that have demonstrated intervals in the 16 to 18ms and there must be a determination if the HIC calculation shall be constrained to 15ms for HIC_{15}. Additionally it might be time to consider a different HIC_{15} threshold for playground surfacing under play structures intended of children under 3 based in the HIC_{15} threshold for the 3 year old dummy of 570 and the HIC_{15} value for the 6 year old dummy being 700. There is injury data to support a reduction for the Gmax to a maximum of 125g and consideration should be given to reducing this to 110g. The separation of impact attenuation values by age group would be consistent with both ASTM F1487 Standard and the CPSC Handbook as age and anthropological differences are used as factors in the rationale that determined the technical performance requirements for play structures targeting the development needs of each age appropriate user group.

Conclusion: Strong consideration should be given to changing the HIC duration, HIC value and Gmax value in ASTM F1292 to the following;

1. HIC changed from HIC_{max} to HIC_{15}
2. HIC threshold changed from 1000 to HIC_{15} threshold 700 for play structures intended for children 5 to 12 years and 570 for play structures for children 2 to 5 years old.
3. Gmax value changes from 200 to 105

The following paper will explore the new research supporting these conclusions and begin to define the limited financial impact that these recommendations will have on the public playground and the benefits overall to playground injuries.

A Discussion of the Current Head Injury Prevention Strategies as it Relates to Concussion and Head Injuries in Children's Playgrounds

A concussion is a serious head Injury that often occurs on playgrounds. Annually playgrounds rank 4th with 226,091 emergency room visits for all playground injuries and 3rd with 16,130 traumatic brain injuries for all ages and for the 5-18 year age group 160,621 injuries requiring emergency room visits and 10,414 traumatic brain injuries for sport and recreation injuries in the years 2001 to 2005. Admissions to hospital during 2001 to 2005 for traumatic head injuries sustained in playgrounds were 529 for all age groups and 349 for ages in the 5-18 range annually.[1] In the single year between July 2000 and June 2001 220,000 playground nonfatal injuries were treated in emergency departments in the United States[2]. It has been suggested that up to 3.8 million children and adults sustain a concussion each year (Langlois, Rutland-Brown, & Wald, 2006) rather than the previously suggested 300,000 (Thurman, Branche, & Sneizek, 1998) and this might be an underestimate due to the challenges in identifying

[1] Gilchrist J, Thomas KE, Wald M, Langlois J, Nonfatal Traumatic Brain Injuries from Sports and Recreation Activities --- United States, 2001 –2005, MMWR Weekly, July 27, 2007 / 56(29):733-737, Center for Disease Control

[2] Gotsch K, Annest JL, Holmgreen P, Nonfatal Sports- and Recreation-Related Injuries Treated in Emergency Departments --- United States, July 2000 – June 2001, MMWR Weekly, August 23, 2002/ 51(33);736-740, Center for Disease Control

concussion, particularly in young children (Gioia, Collins, et al., 2008; Williamson & Goodman, 2006)[3]. In the early part of the 2000s, by far motor vehicle accidents resulted in the greatest number of head injuries and deaths (61%)[4]. Consequently the bulk of the testing programs and studies related to the prevention of all related injuries and in particular head injuries have been done by this industry. More recent information from the United States Center for Disease Control and Prevention (CDC) (2010) indicates that motor vehicles and traffic are now responsible for 17.3% of TBI and 31.8% of deaths due to head injuries and head injuries due to falls have increase to 35.2%[5].

On the playground, the surface is the major contributing factor to impact of the falling child, whether the impact is to the head or directly to a part of the body with sufficient force to transfer to the skull and brain. The following pages are a compilation of various research studies and a thorough discussion of the issues. It is the intent of this paper to present conclusions and recommendations to those responsible for; public health, injury prevention, regulators, and standard writers as to changes that should be made to existing documents for better prevention of severe injuries.

Overview of Head Injury

Statistics indicate that the head injuries and specifically the traumatic brain injury are happening at an alarming rate on playground and athletic surfaces. TBIs are both complex physiological and neurological events that are under reported to a high degree mainly due to the lack of outward physical injury that would involve the traditional ABC's or "airway, breathing and circulation of any first aid course. The complexity of diagnosis of head injury and potential for head trauma on the playground lack of or misdiagnosis of the initial damaging impact, let alone compounded threat of more serious damage caused by secondary or recurring impacts, are very difficult to detect by the untrained persons or even trained persons with the assistance of scientific instruments. To better understand the issue, it will be important to understand and define what TBI is, how to recognize it, and how to treat it. Additionally some of the history related to and advances made in impact attenuation and its relationship to the protection of humans needs to be reviewed. This will involve a closer look at past analysis methods from cadavers and primate studies to more current and sophisticated football helmets studies and injury reconstruction analysis. In the end there must be a universally accepted premise that no one wants to unknowingly seriously injure a child. Standards writing organizations, along with industry and injury prevention organizations must look to set impact attenuation thresholds that protect the child from unreasonably serious injury. It is anticipated that review of the current research and the a conclusions of future research will result in the conclusion that current thresholds for impact attenuation need to be significantly lowered to provide the level of protection provided by the current NHTSA Standards.

Traumatic Brain Injury

[3] Gioia GA, Isquith PK, Schneider JC, Vaughan CG, New Approaches to Assessment and Monitoring of Concussion in Children, Topics in Language Disorders, pp. 226-281, Lippincott Williams & Wilkins, July-September 2009,
[4] Igou S, How Can the Brain be Injured, BrainInjury.com, Montana Publishing, 2011
[5] US CDC, What are the Leading Causes of TBI?, www.cdc.gov/TraumaticBrainInjury/causes.html., June, 2010

The consensus statement from the Zurich, Switzerland International Symposium on Concussion in Sport (CIS) in 2008 defines concussions as “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces”.[6] Concussions have five major features;

1. Concussion may be caused either by a direct blow to the head, face or neck or elsewhere on the body with an “impulsive” force transmitted to the head.
2. Concussion typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously.
3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury.
4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness (LOC). Resolution of the clinical and cognitive symptoms typically follows a sequential course; however, it is important to note that in a small percentage of cases, postconcussive symptoms may be prolonged.
5. No abnormality on standard structural neuroimaging studies is seen in concussion.[7]

The biokinetics that induce a concussion consist primarily of acceleration, deceleration and rotation forces.[8] Although the direct impact with the head is a high risk for a concussion, significant impacts between the body and the impacting surface can also lead to the concussion. This is particularly the case in the activities of children in playground falls and sport related injuries resulting in impact and rotational forces being transferred to brain within the cerebral fluid within the skull. Ultimately the concussion occurs when the brain is moving about inside the spinal fluids due to the force of an impact. The brain can hit the skull from the inside, and that can tear some blood vessels, injure some nerves and even leave some bruises on the brain.[9]

There are three different kinds of concussions that are related to severity and they are labelled as grades of concussions as follows;

- Grade 1 (Mild concussion) – Confusion, dizziness or other symptoms that last less than 15 minutes
- Grade 2 (Moderate concussion) – The symptoms last longer than 15 minutes, but there is not loss of consciousness (LOC)
- Grade 3 (Severe concussion) – There is LOC, even if it lasts only a few seconds or minutes[10]

Obviously this will have a determination of medical treatment sought immediately after the injured child or athlete is stabilized. This could range from total and quiet rest for 15 minutes to immediate transfer to a medical facility or hospital.

[6] Halstead ME, Walter KD and the Council on Sports Medicine and Fitness, Clinical Report – Sport –Related Concussion in Children and Adolescents, Pediatrics, The American Academy of Pediatrics, August 30, 2010
[7] Halstead ME, Walter KD and the Council on Sports Medicine and Fitness, Clinical Report – Sport –Related Concussion in Children and Adolescents, Pediatrics, The American Academy of Pediatrics, August 30, 2010
[8] Halstead ME, Walter KD and the Council on Sports Medicine and Fitness, Clinical Report – Sport –Related Concussion in Children and Adolescents, Pediatrics, The American Academy of Pediatrics, August 30, 2010
[9] Nagy K, What Happen Inside a Child’s Brain When Force Brings a Head and an Object to Meet, Ezinearticles.com
[10] Concussion Facts – causes, diagnosis, and treatment, Pediatrics for Parents, April 2001

Since concussions in children in the play environment are not likely to be immediately detected and that a concussion is a serious head injury, it is important to recognize the symptoms to provide as prompt treatment as possible. First and foremost it is estimated that up to 90% of concussions do not involve loss of consciousness (LOC), however; all concussions result in some constellation of physical, cognitive, emotional, and/or sleep-related symptoms[11]. Secondly it is important to realize that children who are constantly changing developmentally and without good communication skills can sustain a concussion in a play environment (playground, hills, tree climbing, running, jumping, etc.) and are not likely to have the event causing the concussion witnessed by an adult. As a result, the symptoms might be the only determinant that a concussion has occurred. Additionally a concussion by itself cannot be seen on x-rays, CT scans or MRIs[12]. As a result checking for the following symptoms is important;

- Mild to moderate headache
- Blurred vision
- See stars or flashes of light or saw black
- Loss of balance and dizziness
- Nausea and vomiting
- Change in mood, such as laughing, crying or getting angry easily and inappropriately
- Change in the way your child performs in school
- Trouble thinking, does not know time, date, surroundings or what happened before and after
- Short term loss of learned skills such as toilet training
- Decreased energy
- Sudden alteration of sleep
- Paleness
- Easily distracted and poor concentration[13,14]

There are two recognized concussion assessment tools available to parents, caregivers, teachers, coaches and medical professionals. On the international level there is the SCAT2 tool and card that are directed primarily at the athlete aged 10 and over. Alternatively, the US Department of Health and Human Services Centers for Disease Control and Prevention with the program "Heads Up to Schools: Know your Concussion ABDs", provides a Concussion Signs and Symptoms Checklist. This provides a timed assessment of the injured child and recorded resolution of the injury. A critical part of the assessment process and very difficult in children is determining a baseline for the child prior to the injury in the play environment. It is further complicated that young children are constantly changing and baseline data may not be valid for more than 6 months at a time. As a result it is important that the initial assessment is made by a person very familiar with the child. In some activities such as Canadian minor hockey, involving children, there have been serious discussions of performance of baseline assessments prior to the playing season to facilitate, to the extent possible, the symptoms and changes in a concussed child.

[11] Gioia GA, Isquith PK, Schneider JC, Vaughan CG, New Approaches to Assessment and Monitoring of Concussion in Children, Topics in Language Disorders, pp. 226-281, Lippincott Williams & Wilkins, July-September 2009

[12] Sport – Related Concussion: Guidelines for Parents and Caregivers, ThinkFirst-SportSmart Concussion Education and Awareness Committee, May 2010

[13] Jonathan Pitts, Signs of Concussions in Children, HealthGuideance.org,

[14] Sport – Related Concussion: Guidelines for Parents and Caregivers, ThinkFirst-SportSmart Concussion Education and Awareness Committee, May 2010

For medical professionals there is the Pediatric Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), which is the paediatric version of the ImPACT battery of tests developed for the Pittsburgh Steelers (Lovell, Collins & Maroon, 2002)[15]. The paediatric version of ImPACT consists of seven subtests that tap several key areas of cognitive functioning related to concussion, including episodic learning, memory for verbal and visual information, working memory, and reaction time/processing speed[16]. The main reason that this is only used by medical professionals is that it requires computers and trained staff to administer the tests thereby creating another problem in the timely diagnosis of the serious head trauma.

Once a child has been assessed as having a concussion, the next step is treatment. First and foremost is "brain rest" and at least 15 minutes of total quiet for the Grade 1 concussion. It may be likely that the child will have to be removed from all activity and stay home from school and other activities for some time and until symptoms resolve. One concern for parents might be that a child "home from school" without physical injury would be like a holiday, however; total quiet and "brain rest" includes no texting, television, video games, computers or physical activity, etc. They will need to be protected from a second head impact while they are recovering and it is important to inform the child's teachers, coaches or childcare providers about the injury and the precautions that are to be taken. Additionally it will be critical to the child's future that the teachers be informed that the child will likely need some remedial help or catching up on lessons missed while they are recovering and no testing should take place during recovery as this will not reflect the ability of the child.

Recovery will be in steps that will take a minimum of one step per day and would be as follows;

- Step 1 Complete rest until all symptoms have improved.
- Step 2 Light exercises, such as walking or stationary cycling, for 10 to 15 minutes.
- Step 3 Sport-specific activity or open play for 20 to 30 minutes without risk of impact, rotation or jarring.
- Step 4 Move to "on field" practice or play without any physical contact or in the case of the play environment, no jumping or other activities that would generate an impact through the body.
- Step 5 Once cleared by a doctor, move to practice on the field with body contact or in the play environment, open play with normal activity.
- Step 6 Game play or back to the play environment[17].

Should at any time during the stepwise recovery, the child suffer any of the symptoms of the concussion, the child should be removed back to total rest for a minimum of 24 to 48 hours and the recovery process begun again after symptoms are gone. The concern always is the occurrence of a second head injury before the child has fully recovered from the first.

[15] Gioia GA, Isquith PK, Schneider JC, Vaughan CG, New Approaches to Assessment and Monitoring of Concussion in Children, Topics in Language Disorders, pp. 226-281, Lippincott Williams & Wilkins, July-September 2009
[16] Gioia GA, Isquith PK, Schneider JC, Vaughan CG, New Approaches to Assessment and Monitoring of Concussion in Children, Topics in Language Disorders, pp. 226-281, Lippincott Williams & Wilkins, July-September 2009
[17] Healthy Active Living Committee, Identification and management of children with sport-related concussion, Canadian Paediatric Society (CPS), Paediatr Child Health 2006: 11(7):420-8, revised January 2010

Where the concussion is a Grade 2, or 3, the recovery may take weeks or months. In some high profiles sports cases in hockey and football, participant's concussions have been season and career ending. In the case of a child studies have shown that recovery from concussions are slower and take a longer duration for full recovery than adults. Studies comparing NFL players with high school football players indicate that the NFL players returned to base line within a week and many returned to normal performance two days after the injury, while high school athletes demonstrated slower injury recovery and longer lasting neuropsychological effects[18]. Since younger children are changing in ability, behaviour and personality, the determination of full recovery is often complicated.

The effects of multiple and cumulative effects of concussions have been studied in organized sports rather than play environments. The risk and consequences of multiple concussions on children in a play environment are difficult due to the injury not being regularly witnessed and when they occur they are significantly under reported. In sports and athletics there is the ability to have trainers and coaches capture the data and record the events as they occur. High School athletes with three or more prior concussion were more likely to experience on-field positive loss of consciousness, anterograde amnesia, and confusion following a subsequent cerebral concussion[19]. One of the authors of the foregoing study, Dr. Michael Collins, director of the University of Pittsburgh Medical Center's Sports Medicine Concussion Program states that six to eight high school football players die each year because of "second impact syndrome."[20] Repeated concussions without full recovery are considered to have led to clinical depression, mental illness and premature death in former football players and boxers. The study involving 2,488 retired NFL players with an average age of 58, and average NFL career of 6.7 year, 61% had sustained at least one concussion and 30% had suffered more than three. Of these 2,488 athletes, 263 (11%) had been diagnosed with clinical depression.[21] Professional boxers receive repeated blows at approximately 52 g's which has been equated to being hit with a 13lb (5.9kg) bowling ball traveling at 20 mph (32kph).[22]

Current Guidance for Playground Safety Surfacing Requirements

The fact that concussions occur in playgrounds and are serious head injuries with the potential of life-changing consequences for the child is irrefutable. Concussion symptoms are ten times more likely to go underreported and left untreated in instances where there is no external physical manifestation as perceived by the child's caregiver. Familiarity with the child's moods, habits and other behaviours may be critical to form a baseline in determining a change that could be related to a concussion. As a result it is important to investigate the forces that cause a concussion and methods of measurement in the field In order to minimise the frequency and severity that may result from the playground fall and subsequent injury.

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[18] NFL Players Show More Rapid Recovery from Concussions than High School Players, University of Pittsburgh Medical Center, UPMC News Bureau, January 23, 2006

[19] Collins MW, Lovell, Iverson GL, Cantu R, Maroon J, Field M, Cumulative Effects of Concussion in High School Athletes, Neurosurgery, 2002

[20] Craig M, Medical Field Helping NFL to Learn About Concussions, Birf.info, August 2006

[21] Kuwana E, Long-Term Effect of Consussion in Football Players, Faculty of Life Science, NYMU

[22] Igou S, How Can the Brain be Injured, BrainInjury.com, Montana Publishing, 2011

Determination of Impact Attenuation Values in Standards

To start the discussion a summarization of various playground standards' scope in relation to injury protection statements, testing procedures and performance requirements must be considered. The US Consumer Product Safety Commission (CPSC) was the first to publish a value for impact attenuation in the 1981 "Handbook for Public Playground Safety, vol.1&2" with the recommendation that from a maximum estimated fall height, the Gmax should not exceed 200 g's to an ANSI headform.[23] In the 1980s the ASTM F08 Committee on Sports Equipment and Facilities created a task group on playground surfacing, which evolved to the F08.63 Subcommittee on Playground Surfacing. Their first standard, the ASTM F1292 standard was published to outline the laboratory and field test methods for playground surfacing and the determination of a critical height. In 1991, CPSC revised the "Handbook for Public Playground Safety" and included a recommendation that not only is peak acceleration (Gmax) important, but so too is the duration of the acceleration. Subsequently, the 1993 revision of ASTM F1292 included both a Gmax of 200 and HIC of 1000 as the maximum threshold for determination of critical height for playground surface materials/systems.

It should be noted that the selection of the Gmax 200 is based on primates, large animals and cadaver studies. Although these subjects have been used throughout medical history and continue today, the early studies using cadavers and sub-human primates in the study of head impact dates back to World War II. Many studies investigated the relationship between linear accelerations and damage to the skull or brain. In one such study in the late 1950's the US Air Force performed studies on anesthetised hogs, which indicated that impacts with duration of 4 to 8ms and impacts up to 125g showed reversible injuries, while impacts ranging up to 220g and the same duration resulted in serious to fatal injuries.[24] Similar studies at Wayne State University resulted in the development of the Wayne State Tolerance Curve (WSTC), a roughly logarithmic curve that describes the relationship between the magnitude and duration of the impact acceleration and the onset of skull fractures, in the early 1960s[25].

The WSTC has formed the basis of mathematical modeling for development of injury tolerance curves and better understanding the injury data that are now being produced by the human surrogate (crash test dummies). The first major advance in the development of mathematical models was the plotting of the WSTC on log paper by Gadd, resulting in an approximately straight line function for the weighted impulse criterion and this became known as the Gadd Severity Index (SI).[26] In 1972, the National Highway Traffic Safety Administration (NHTSA) defined the relationship between the WSTC and the SI as modified by Versace in 1971 as the Head Injury Criteria (HIC)[27]. Prasad and Mertz compared a collection of skull fracture and brain injury data with their corresponding HIC values and suggested that

[23] Shiffer RC, ASTM F-1292 as tool for playground injury severity reductions, Head and Neck Injuries in Sports, ASTM, 1994
[24] Lt. Col. John Stapp, M.C., Human Tolerance to Deceleration, American Journal of Surgery, Volume 93, April 1957
[25] Shorten M, PhD, Himmelsbach JA, Sports surfaces and the risk of traumatic brain injury, BioMechanica, LLC, Portland, Oregon,
[26] McHenry BG, Head Injury Criterion and the ATB, ATB User's Group, 2004, pages 3 to 8
[27] McHenry BG, Head Injury Criterion and the ATB, ATB User's Group, 2004, pages 3 to 8

at a HIC value of 1000 there is a 16% risk of life-threatening brain injury in the adult population[28]. The HIC value of 1000 has been used as the pass/fail in a number of performance standards for prevention of life-threatening injury[29,30,31] in the measurement of impact attenuating surfaces in playgrounds, without consideration of the 1000 HIC value being the tolerance threshold for the adult male. Although there should have been consideration of scaling the value to the age group of the playground, 18 months to 12 years[32,33] the selection of the 1000 value was based on HIC becoming a dominant injury prevention mechanism and from the view point of the ASTM F08 Committee developing the F1292 standard the request to utilize the HIC 1000 threshold was at the request of the CPSC[34]. The use of the 1000 HIC in these standards had been perpetuated by tradition and has only begun to be called into question in the ASTM F08.63 sub-committee in 2010. It has also been believed that HIC of 1000 was the threshold for life-threatening, when it is actually 16% beyond.

For the last 30 years, the playground industry has been dominated by the companies who design and produce play structures, making the issue of setting appropriate protective surfacing a side issue to be taken into consideration by the owner later in the design process. Requirements for playground surfacing performance in the field after installation has followed two tracks of development. The first track has brought about the evolution of technical requirements for performance to a test procedure for impact attenuation, initially recommended by the CPSC[35]. The second was to adopt the presumably parallel guidance provided in the CPSC. The 1991 revision of the pubic playground safety handbook provides a table of commonly used loose-fill surfacing materials and the depths (9 inch compressed and uncompressed) at which they were tested which resulted in establishing each surface material's critical heights[36]. The table was republished in subsequent revisions of the same handbook[37] through November 2010. This table has gained general consumer use as a substitute for ASTM F1292 and was so popular as a measure of performance that it has been adopted as part of the technical requirements of Canadian Standards Association (CSA) Z614-98[38]. Use of the table by the general public has put the focus was on the critical height table and not the descriptive information of the samples that were tested. It was later discovered that the materials as described were not necessarily commercially available in all juristictions and this resulted in the removal of the surfacing Table 1 from the CSA Z614-03.[39] A version of this table was revised and published by the CPSC base upon nine (9) inches of compacted loose-fill materials. This

[28] Cozy CZ, Jones MD, Development of a simulation system for performing in situ tests to assess the potential severity of head impact from alleged childhood short falls, Forensic Science International, 2006
[29] ASTM F1292-93, Standard Specification for Impact Attenuation of Surfacing Materials Within the Use Zone of Playground Equipment, ASTM, 1993
[30] CSA Z614-98, Children's Playspaces and Equipment, Canadian Standards Association, 1998
[31] En1177:1997, Impact attenuating playground surfacing – test methods, CEN, 1997
[32] CSA Z614-98, Children's Playspaces and Equipment, Canadian Standards Association, 1998
[33] ASTM F1487-93, Standard Consumer Safety Performance Specification for Playground Equipment for Public Use, ASTM, 1993
[34] Shiffer RC, ASTM F-1292 as tool for playground injury severity reductions, Head and Neck Injuries in Sports, ASTM, 1994, p340
[35] US CPSC, A Handbook for Public Playground Safety, Volume 2: Technical Guidelines for Equipment and Surfacing, US CPSC, 1981, p22
[36] US CPSC, Public Playground Handbook for Safety, US CPSC, 1991, p21
[37] US CPSC, Public Playground Handbook for Safety, US CPSC, 1997. P5
[38] CSA, CAN/CSA-614-98, Children's Playspaces and Equipment, 1998, p97
[39] CSA, CAN/CSA-614-03, Children's Playspaces and Equipment, 2003, p46

chart continues to mislead the general public who fails to evaluate and compare the characteristics of these common materials against those used to create the CPSC Table 1. Failure to remove or adequately revise this table and move their recommendation to a technical compliance with ASTM F1292 will continue to perpetuate this non-technical track and potentially result in continued severe head injuries.

Generally speaking, it has been thought that any changes in recommendations to improve the impact attenuation performance of the protective surface resulted in an increase in the cost of the compliant protective surfacing. This has had the effect of increasing the percentage of the playground budget being spent on the protective surfacing. In the 1970s and early 80s a grass, sand or pea gravel surface was less than 1% of the total playground budget, whereas in 2010 there are playgrounds being installed with sophisticated rubber surfacing systems that consume more than 50% of the total budget for the playground. Protective surfacing critics believe the new emphasis on protective surfacing has had a negative impact on the overall number of play areas and the magnitude of play components sold thereby significantly afftecting the financial performance of the corporations who make them.

At present time there are very few large play structure manufacturing entities that supply both play structures along with a full range of playground protective and/or accessible surfacing systems. Generally the more traditional economic business model is that the manufacturer builds a nationwide network of dealers and distributors. These dealers then establish independent relationships with providers of a diverse range of surfacing systems. As a result the profit related to the growing proportion of the overall playground budget going to surfacing is in the hands of the dealer rather than the manufacturer. This model is likely to change as competition, performance requirements, sophistication of installation requirements, warranties and economies of scale increase. Owner/operators and manufactures will have to pay greater attention to the protective surfacing primarily since 68 % of the injuries that occur on public playground equipment involve falls, primarily to the surface below the equipment[40]. Additionally, the Americans with Disabilities ACT, now a U.S. federal law (DOJ 2010 Standard for Accessible Design), specifically requires playgrounds create an accessible route within the use zone of the actual playground and its use zone must comply with and be maintained to ASTM F1292 and ASTM F1951.

All playground standards throughout the world make statements with regard to promoting challenging play within a “safe” environment or have a stated intent of protecting the child from “unforeseen hazards”. While it is important to make a statement regarding the “safety of children” or providing “safe play conditions” or protection from “unforeseen hazards”, there is a failure to clearly define the words safe, safety, unforeseen consequence, or hazard in relation to injury prevention or what is an acceptable severity of injury. In North America, both the ASTM and CSA standards make statements within their scopes with regard to the standard of injury prevention intended through the use of their performance specifications. For the CSA Z614-07, section 1.3 of the scope states “This Standard contains recommendations on technical requirements and practices applicable to the design, manufacture/construction, installation, maintenance, and inspection of public-use playground equipment and playspaces. The specifications laid out in this Standard are intended to minimize the

[40] Tinsworth DK, McDonald JE, Special Study; Injuries and Deaths Associated with Children’s Playground Equipment, US CPSC, April 2001, piii

likelihood of debilitating and/or life-threatening injuries.[41]" ASTM F1487 in section 1.1 of the scope states "This consumer safety performance specification provides safety and performance standards for various types of public playground equipment. Its purpose is to reduce life-threatening and debilitating injuries."[42] with the 1000 HIC being 16% above the threshold for life-threatening, let alone debilitating.

Alternatively the F08.63 sub-committee on Playground surfacing has been very careful in the injury prevention statements being made in its standards and provides guidance to the user as to the severity of the potential injury and better practices. ASTM F1292, Section 1.1 of the scope, only makes statements to the effect that this specification establishes minimum performance requirements for the impact attenuation of playground surfacing installed within the use zone of playground equipment". It clearly states in section 4.4.3 that the owner/operator may choose to have the surface they are considering to install to have better performance than the minimums in the Standard. To reinforce this, statement the ASTM F08.63 sub-committee has since 2003 published and actively maintains the ASTM F2223, Standard Guide for ASTM Standards on Playground Surfacing which in section 7.2 (impact attenuation) states, "lower values of g-max and HIC signify better performance for impact absorption"[43]. Additionally, ASTM F1292 requires that the owner/operator stipulate the drop height for testing in the field and encourages that that drop height be greater than the minimums set in the relevant play structure standards for fall height. There is also a statement in 4.4.3 that, "the specifier is permitted to specify additional impact attenuation performance requirements, providing that such additional performance requirements are more stringent than the performance requirements of this specification"[44]. As warning and instruction, ASTM F1292 provides a requirement that should a surface within the use zone not comply with the Standard "the play structure shall not be permitted to be used until the playground surface complies."[45] As a result the F0.63 sub-committee has been the provider of much greater technical requirements, interpretation, best practice and clear statements as to the consequences associated with the failure of the playground surface to comply.

ASTM F1292 mission is directed at reducing the 68% of total playground injuries related to falls to the surface, yet the standards, ASTM F1487, CSA Z614, and guides, CPSC document #325, are the predominant resources on playground environment for manufacturers and teaching organizations, leading to concentration on the structures and play components from a technical, performance inspection and testing viewpoint. As an example the most well-known teaching organization for playground compliance in the United States, the National Recreation and Parks Association (NRPA), Certified Playground Safety Inspector (CPSI) course is based on the ASTM F1487, ASTM F2223, and the CPSC Handbook for Public Playground Safety[46]. Although they provide two training modules on performance requirements and use zone requirements it is difficult to understand why there is not more course content devoted to the performance or compliance requirements within these documents addressing the more prominent risk factor of injury from falls. Effectively this leaves the playground owner/operator relying on compliance and therefore injury prevention based on the pass/fail results and values of a one-time product samples successfully tested in a laboratory controlled environment.

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[41] CSA Z614-07, Children's Playspaces and Equipment, Canadian Standards Association, 2007

[42] ASTM F1487-07a, Standard Consumer Safety Performance Specification for Playground Equipment for Public Use, ASTM, 2007

[43] ASTM F2223-03, Standard Guide for ASTM Standards on Playground Surfacing, ASTM, 2003

[44] ASTM F1292-09, Standard Specification for Impact Attenuation of Surfacing Materials Within the Use Zone of Playground Equipment, ASTM, 2009, p4

[45] ASTM F1292-09, Standard Specification for Impact Attenuation of Surfacing Materials Within the Use Zone of Playground Equipment, ASTM, 2009, p4

[46] NRPA, CPSI Course Materials, 2011

ASTM F1292 is required in ASTM F1487 Standard within the following sections;

- 9.1.1 Layout a use zone with obstacle free surfacing that conforms to F1292,
- 11.2.2 Install protective surfacing in the use zone compliant with F1292
- 13.2.1 Maintain the protective surfacing in the use zone to comply with F1292
- 14.3 Apply a label to inform, warn, and educate purchasers, installers and those supervising children who play on the equipment about the ongoing danger of installing equipment over hard surfaces and to serve as a constant reminder to provide and maintain appropriate surface as identified by F1292

Essentially these sections are not instructive as to the injuries (life-threatening head injury) that ASTM F1292 is set to prevent or that there might be a better practice with regard to injury prevention.

With regard to the most recent revision of the CPSC Public Playground Safety Handbook (document #325), this clearly states in the definitions section that critical height is "the fall height below which a life-threatening head injury would not be expected to occur.[47] Further in section 2.4 on surfacing it provides that;

> "Testing using the methods described in ASTM F1292 will provide a "critical height" rating of the surface. This height can be considered as an approximation of the fall height below which a life-threatening head injury would not be expected to occur. Manufacturers and installers of playground protective surfacing should provide the critical height rating of their materials. This rating should be greater than or equal to the fall height of the highest piece of equipment on the playground. The fall height of a piece of equipment is the distance between the highest designated play surface on a piece of equipment and the protective surface beneath it."[48]

The Handbook differs from ASTM F1487 in a number of material ways; first that non-compliance could have life-threatening consequences, and secondly that the drop height for any structure within the playground as a minimum should be performed at the fall height of the highest structure within the playground or the highest portion of a composite structure. This usually provides more impact attenuation for the play equipment with a lower fall height than the highest play component in the playground. This scenario would still place the performance of the surfacing system for the highest structure at the life-threatening level. Generally the highest fall height of the playground will be 8' to 10' depending upon the selection of swings, slides and climbers.

It could be that persons with some training and general understanding, of ASTM F1487 and the CPSC Handbook are of the belief that the performance of testing to ASTM F1292 is not important or their responsibility and they can rely upon the manufacturer of the surface system or can replace the need for field testing their surface system with the critical height table in the CPSC Handbook or they may be making an assumption that their existing surfaces continue to provide the required protection as required in ASTM F1292 years after installation. This has resulted in significantly fewer people having in their possession the technical documents of the ASTM F08.63 sub-committee. Unfortunately the impact attenuation in playgrounds in California in 2006 "found a 69% failure rate for rubberized California playground surfaces using attenuation standards.[49] This failure was most often relate to the surface test performance at the fall heights of the play equipment with the highest fall heights, generally greater than eight (8) feet. It is anticipated that awareness of ASTM F1292 and ASTM F1951 will rise as they

[47] US CPSC, Public Playground Safety Handbook, CPSC, 2011, p3

[48] US CPSC, Public Playground Safety Handbook, CPSC, 2011, p8

[49] Evaluation of Health Effect of Recycled Waste Tires in Playground and Track Products, Integrated Waste Management Board, 2007, p3

have now been mandated as two of many performance requirements for the installed ground level accessible route on the playground surface[50].

Defining the Measurement of the Life-Threatening

The development of the impact attenuation criteria used to measure impacts on playground surfaces have almost exclusively been based on the crash tests data produced in the automotive industry with a minor confirming reliance on some military testing. There is significant evidence that a direct impact with the head or an impact to the body with sufficient energy to transmit the force of the impact to the head, combined with sufficient linear or rotational acceleration within an interval of duration in milliseconds, will result in a severe head injury. Historically this was determined with animal and cadaver studies with the result being the WSTC, the Gadd SI and the HIC. This has remained the commonly accepted threshold since the 1970s and 80s for reducing the risk for a life-threatening or permanently life threatening head injury. This HIC value of 1000 was at the time based on the large adult male. There were no other data or scaled values available. Additionally the HIC calculation was not constrained as to the duration of the interval of the impact. Even so this calculation was then translated to ASTM F1292[51]. Since 1993 there have been significant advances in the evaluation of head injury and the impact threshold values related to an acceptable injury severity.

In October of 1986, the National Highway Traffic Safety Administration (NHTSA) recommended the calculation of HIC be constrained to 36 milliseconds (HIC_{36}) since longer intervals had not shown low probabilities of injury in voluntary human subject tests and the HIC of 1000 for the unconstrained HIC would be roughly equal to HIC_{36} 1000. Additionally the test data for head impacts studied by Prasad and Mertz in 1985, Hodgson in 1973 and 1997, Got in 1978 and Tarriere, were all found to have short duration impacts, which were less than 12 milliseconds[52]. As a result both the HIC_{15} and HIC_{36} could be applied to the data. It was determined by the industry group making recommendation to the NHTSA that the limit values more related to the HIC_{15} and should be applied with the maximum HIC value for the mid-sized male being <700[53]. Through scaling it was determined that the HIC_{15} values for various dummy sizes would be as in Table 1[54]. The values in Table 1 have been adopted by the NHTSA as of the final rule making in March of 2000.[55]

Dummy Type	Large Adult Male	Mid-Sized Male	Small Female	6 year old child	3 year old child	1 year old child

[50] U.S. Department of Justice, 2010 ADA Standards, September 15, 2010, page 10

[51] Shiffer RC, ASTM F-1292 as tool for playground injury severity reductions, Head and Neck Injuries in Sports, ASTM, 1994, p340

[52] Eppinge R, Sun E, Bandak F, Haffner M, Khaewpong N, Maltese M, Development of Improved Injury Criteria for the Advancement of Automotive Restraint Systems – II, National Transportation Traffic Safety Administration, Nov. 1999, p 2-1

[53] Eppinge R, Sun E, Bandak F, Haffner M, Khaewpong N, Maltese M, Development of Improved Injury Criteria for the Advancement of Automotive Restraint Systems – II, National Transportation Traffic Safety Administration, Nov. 1999, p 2-9

[54] Eppinge R, Sun E, Bandak F, Haffner M, Khaewpong N, Maltese M, Development of Improved Injury Criteria for the Advancement of Automotive Restraint Systems – II, National Transportation Traffic Safety Administration, March 2000, 2-2

[55] Eppinger R, Sun E, Kuppa S, Supplement: Development of Improved Injury Criteria for the Advancement of Automotive Restraint Systems – II, National Transportation Traffic Safety Administration, March 2000, pS1-1

HIC_{15} Limit	700	700	700	700	570	390

Table 1: HIC_{15} limits for Crash Dummies of various types

To provide a measure of understanding for Table 1 it is instructive to review the Abbreviated Injury Scale (AIS) and the HIC_{15} thresholds. The AIS was first developed in 1971 to aid vehicle crash investigators in quantifying injury severity and assigning a numeric value and these values are applied to 5 body regions, including the head. AIS injury score runs from 1 to 6 as outlined in Table 2.[56]

Injury Severity	**Abbreviated Injury Score**
Minor injury	1
Moderate injury	2
Severe, but not life-threatening	3
Potentially life-threatening, but survival likely	4
Critical with uncertain survival	5
Unsurvivable injury (maximum possible)	6
Severity unknown	9

Table 2: Abbreviated Injury Scale (AIS)

Although the AIS is applied to 5 portions of the body and then modified to provide the Injury Severity Score for the trauma patient we will only be considering the descriptive symptoms associated with the head and neck and the score from 3 to 5 in table 3.[57]

Severity of Injury Symptom	Body part	AIS
Cerebral injury with or without skull fracture, with unconsciousness more than 15 minutes, without severe neurological signs, brief post-traumatic amnesia (<3 hours	Head and neck	3
Displaced closed skull fracture without unconsciousness or other signs of intracranial injury	Head and neck	3
Loss of eye	Head and neck	3
Avulsion (forcible detachment) of optic nerve	Head and neck	3
Displaced facial bones fractures or those with antral or orbital involvement	Head and neck	3
Cervical spine fracture without cord damage	Head and neck	3
Cerebral injury with or without skull fracture with unconsciousness of more than 15 minutes, with definite abnormal neurological signs; post-traumatic amnesia 3-12 hours	Head and neck	4
Compound skull fracture	Head and neck	4
Cerebral injury with or without skull fracture, with unconsciousness of more than 24 hours; post traumatic amnesia more than 12 hours	Head and neck	5
Intracranial Hemorrhage	Head and neck	5
Signs of increased intra-cranial pressure (decreasing state of consciousness, bradycardia under 60, progressive rise in blood pressure or progressive pupil inequality	Head and neck	5

Table 3: Head and neck injury symptoms for AIS 3 and 4

[56] Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS), Medal Military Medicine, Medal.org Ltd, p1
[57] Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS), Medal Military Medicine, Medal.org Ltd, p 2-3

During the 1990s, automotive researchers made significant advances in the understanding of injury assessment reference values (IARVs), which were originally developed by Mertz in 1978 and revised in 1993 for response measurement of the Hybrid III small female and large adult male test dummies[58]. Other IARVs were developed for Hybrid III child test dummies. Prasad and Mertz have published injury risk curves for skull fracture and for AIS ≥4 brain injury due to forehead impacts based on the HIC15 criterion and for skull fracture based on peak g center of gravity acceleration.[59] The result is the HIC_{15} value of 700 is a conservative estimate of the 5% risk level of AIS ≥4%[60], the current automotive standard in the United States and Canada.

Present playground surface performance is also partially based on the Gmax of 200, which is based on the US CSPC recommendation for eliminating life-threatening head injuries if that surface could be maintained below this threshold value. It important to review the risk assessment associated with this value of Gmax. Studies by Mertz et al (1997) estimated a 5% risk of skull fractures for a peak acceleration of approximately 180g and a 40% risk of a skull fracture for a peak acceleration of 250g.[61] A study by Chan et. al. determined that there is a 15% risk of skull fracture at 124g, with a 95% confidence level[62], while Haddadin et al, found a 5% risk of an AIS ≥3 at 72g and a risk of 20% of an AIS ≥3 at 88g[63]. Another factor that might be considered in evaluating the use of 200 g's as the threshold limit for ASTM F1292 is that data has indicated that on average, a Gmax score of 150 is equivalent to a HIC score of 1000.[64] This could well be a factor in the final selection for Gmax for ASTM F1292.

Clearly concussions and AIS >4 thresholds are not the same. It must be determined as to whether the goal is the prevention of the AIS >4 or the TBI before a thresholds for both Gmax and HIC_{15} can be established in a standard for children in a playground. Concussion studies have mostly been related to data collected from teenagers, college athletes and reconstructions of concussions sustained by NFL players. Children pose a unique challenge, because their brains are still developing and more susceptible to the effects of concussion[65] and children and high school athletes recover less rapidly than NFL players[66].

There have been two major studies, termed the NFL study, using a small sample of injured players and specific concussion incidents, and the HITS (head impact telemetry system) studies, involving a large number of athletes and thousands of head impacts. Although the conclusion of concussions in football

[58] Mertz HJ, Injury Risk Assessment Based on Dummy Response, Nauham and Melvin 2nd Edition, Accidental Injury, Chapter 5, Springer 2002, pp 89

[59] Mertz HJ, Injury Risk Assessment Based on Dummy Response, Nauham and Melvin 2nd Edition, Accidental Injury, Chapter 5, Springer 2002, pp 89

[60] Mertz HJ, Injury Risk Assessment Based on Dummy Response, Nauham and Melvin 2nd Edition, Accidental Injury, Chapter 5, Springer 2002, pp 90

[61] Kleiven S, Finite Element Modeling of the Human Head, Department of Aeronautics, Royal Institute of Technology, 2002, p15

[62] Chan P, Lu Z, Rigby P, Takhounts E, Shang J, Yoganandan N, Pintar F, Development of a Generalizes Linear Skull Fracture Criterion, 2007, 910

[63] Haddadin S, Albu-Schaffer A, Hirzinger G, Safety Analysis for a Human-Friendly Manipulator, Springer Science & Business Media, 2010, p241

[64] Shorten M, Phd, Discuss impact Performance of Playground Surfaces on November 8, Standardization News, ASTM , Movember 2002,

[65] Halstead et. al., Clinical Report – Sport-Related Concussion in Children and Adolescents, American Academy of Pediatrics, Sept. 2010, p597

[66] Manko S, NFL Player Show More Rapid Recovery from Concussion than High School Players, University of Pittsburgh Medical Center, Jan. 2006

are somewhat different, they both consider the incidence of the concussion to be well below the 200 Gmax thresholds for turf in ASTM standards, Interestingly both of these studies have consistently included the HIC values as very important in understanding the incidence of concussion.[67] This might be a surprise to some involved with the athletic turf, either natural or synthetic as turf is only tested to Gmax with either a the "Clegg Hammer" or the "F355-A device"[68]. These devices can only record Gmax, due to the flat shape of the impacting surface. It has been shown that the "F355-A device" is bias in favour of thin soft surfaces, whereas when the data is adjusted to provide an HIC, these thin systems demonstrate a significantly higher injury risk than the thicker systems with infill and/or padding underlayment.[69]

The NFL study, as it has become to be known, reconstructed 31 NFL collisions of which the 25 impacts involved concussions[70]. These impacts were modelled and impact data generated at the laboratories of Biokinetics and Associates in Ottawa, Canada using helmeted Hybrid III test devices, with concussions occurring at 98g $\pm$28g and HIC of 250[71]. These results were tested as the object of the study by Zhang et.al.(2004) in which they used finite element (FE) modeling technique and the Wayne State Brain Injury Model (WSUBIM) to determine Gmax, HIC_{15} and rotational acceleration. Their results were that for the injured athlete the mean acceleration was 103 $\pm$30g, the HIC_{15} 441 $\pm$224 and the mean rotational acceleration was 7354 $\pm$2897 rad/s^2.[72] Criticism of using these values is that they have subsequently become known as the injury threshold for concussion rather than exclusively descriptive of the values specifically related to known concussions. This may well be a valid argument, but the evidence demonstrates concussions are taking place at these values for elite athletes with exceptional protective equipment, training and conditioning. This would not likely be the case for the child in the playground or the high school or college athlete.

Another perspective on the risk of concussion is the analysis of injury and impact data collected through the deployment of the HITS data collection devices in football helmets of a large number of athletes. These studies have the ability to collect thousands of impacts and provide data for Gmax, HIC_{15} and rotational acceleration for each impact. At some point there is the inevitable occurrence of the concussion and the impact data prior to the concussion is available for statistical analysis. Through the comparison of impact values for those sustaining concussion and those not, it is possible to determine that there is a 10% risk of concussion for Gmax of 165 and HIC_{15} of 400[73]. This could lead to the conclusion that for some athletes other factors allow them to sustain higher values of peak acceleration without sustaining a concussion; however in a study of 1712 impacts[74], in which no concussions were sustained, there were only 3 impacts greater than 100 g's and only 1 of these was over 120 g's. Other

[67] J. R. Funk, S.M. Duma, S. J. Manoogian, S. Rowson, Biomechanical Risk Estimates for Mild Traumatic Brain Injury, Association for the Advancement of Automotive Medicine, October 2007, p1

[68] Shorten M PhD, Himmelsback JA, Sport surfaces and the risk of traumatic brain injury, Biomechanica LLC, 2002, p59

[69] ShortenM PhD, Himmelsback JA, Sport surfaces and the risk of traumatic brain injury, Biomechanica LLC, 2002, p63

[70] Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF, Concussion in professional football – Recontruction of game impact and injuries, Neurosurgery, 2003, PP799-814

[71] Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF, Concussion in professional football – Reconstruction of game impact and injuries, Neurosurgery, 2003, PP799-814

[72] Zhang L, Yang KH, King AI, A Proposed Injury Threshold for Mild Traumatic Brain Injury, ASME, April 2004, p228

[73] Rowson S, Brolinson G, Goforth M, Dietter D, Duma S, Linear and Angular Head Acceleration Measurements in Collegiate Football, ASME, June 2009, p1

[74] Rowson S, Brolinson G, Goforth M, Dietter D, Duma S, Linear and Angular Head Acceleration Measurements in Collegiate Football, ASME, June 2009, p3

than these 3 impacts the study would tend to lend credibility to NFL values to for value below which no concussion is anticipated. This same study shows a high correlation between increasing peak acceleration[75] and increases in the angular acceleration, indicating that if rotational acceleration is a factor in concussions, the increasing g value could be a predictor of the angular acceleration.

These studies introduce an additional criterion to the traditional linear acceleration for Gmax and impact duration of the HIC, with the rotational acceleration. Rotational acceleration recognizes that most impacts, particularly between athletes that the impact will be from a side or glancing and there will be an impact that is not strictly coup/countercoup, but will allow the brain to move rotationally within the skull and can cause shearing of the neurons axon, damaging the protective myelin coating and disrupting communication between cells[76].

The HITS instrumented helmets have increased the data available to coaches, trainers and team physicians in the monitoring of potential risk of head injury to their athletes. Data collected over the 4 year period from spring 2005 to fall 2008 resulted in 71,390 impacts with a total of 55 concussions being caused at Gmax 107 ±31, HIC_{15} 272 ±213 and 7,079 rad/s^2 ± 3,408 rad/s^2.[77] In a presentation to the Federal Interagency Conference on TBI, Beckwith presented additional data for the six years 2005 to 2010 in which there are now 90 concussions and they are occurring at a peak g of 117 ±33 and 7266 rad/s^2 ±3,400.[78] The HITS helmets indicate that there are impacts greater than the mean g's for those sustaining concussions. These results must give all professionals; particularly those in states that have a legal responsibility for the prevention of concussions in their athletes, an exceptional opportunity meet their responsibilities.

The data, whether it is from the NFL study or the HITS results, shows that a threshold exists between 70 and 150 g's where concussions are occurring, and the median is likely to fall in the 105 to 110g range. These values are significantly lower than the threshold for the playground surface as required in ASTM F1292 of 200 g's.

On the basis of the data, this would translate that the Gmax of a play surface when tested should be less than between 105 and 110 and from the automotive requirements for HIC_{15} should be less than 570 for the structures intended for children 2-5 years and less than 700 for children 5-12 years. These values would prevent the AIS >4 head injury.

Implications for Long Bone Injuries

Beyond the discussion of concussion, there is a documented need "to evaluate various protective surfaces in terms of reducing fractures to the wrist, lower arm and elbow"[79] by Tinsworth (2001). Long bone injuries are common on playgrounds. The ASTM F08.63 sub-committee has frequently stated that these types of injuries would be a realistic expectation given the current allowable impact values. The F2223 Guide states in Section 7 that is directed at the F1292 impact attenuation Standard that "It should

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[75] Rowson S, Brolinson G, Goforth M, Dietter D, Duma S, Linear and Angular Head Acceleration Measurements in Collegiate Football, ASME, June 2009, p3

[76] Ogilvie M, The Brain, Why a Blow to the head is a big deal, The Toronto Star, April 9, 2011. pIN 1 & 5

[77] Beckwith JG, Chu JJ, Crisco JJ, McAllister TW, Duma SM, Brolinson PG, Greenwald RM, Severity of Head Impacts Resulting in Mild Traumatic Brain Injury, p2

[78] Beckwith JG, Severity of Head Impact Preceding Diagnosis of MTBI, Federal Interagency Conference on TBI, June 2010, abstract

[79] Deborah K. Tinsworth, Joyce E. McDonald, Special Study; Injuries and Deaths Associated with Children's Playground Equipment, US CPSC, April 2001, piii

be recognized that serious injuries (for example, long bone injuries, etc.) might occur even though the playground surfacing system meets the requirements of Specification F1292."[80] A recent study of children 1 to 17 years and running from 2003 to 2006 in Washington, DC, concluded that "Playground falls and minor trauma are implicated in the majority of childhood fractures" and "the prevention strategies should target playground safety."[81] As a result it can be expected that long bones will continue to the broken unless changes are made to the cause of the injury, the surface upon which the child lands.

Although it is not within the scope of this paper to provide a long investigation of the causes and impact attenuation factors related to long bone injuries, it might be instructive to review some of the literature to determine if the changes to impact attenuation standards in playgrounds would also have a positive outcome in relation to long bones. Studies related to primarily arm fracture in the playground and taking impact attenuation into consideration have primarily been in Canada and Australia, while there is a wealth of biomechanical fracture information in the United States within the study of injuries related to child abuse. It is interesting that depending upon the circumstances of the location of the injury taking place it could be considered as "just another playground injury" or child abuse. In 1995 in Montreal, Canada impact values were recorded at 102 playgrounds where 110 serious injuries to the head and fractures (AIS 2 or 3) were investigated. The Gmax that was recorded and the risk of serious injury was 3 times greater for impact values above 200g than for values as compared to surfaces yielding a Gmax <150 and 1.8 times greater in the 150-199g category as compared to the <150 category[82]. This resulted in a recommendation that playground standards should consider reducing the Gmax threshold from 200g to 150g or less[83]. Sherker and Smith (2004) found that of the arm fractures studied that >86% occurred in playgrounds that were compliant to playground impact standards. Additionally the mean impact values were 119g and the HIC was 615.[84] Sherker et. al. (2005) found that peak acceleration of 100G and above represented an arm fracture risk approximately 1.5 times that of less than 100g for tests conducted using both an instrument headform compliant with standards and an anthropometric child arm load dummy.[85] Fiissel et. al. (2007) indicated that >85% of major fractures in children occur in playgrounds seen at the Hospital for Sick Children in Toronto, Canada for the years 1995 to 2002 and the injury risk was 3.91 times greater for a fall from playground equipment than from standing height on the playground.[86]

Consideration of the forces and dynamics of fractures as a result of child abuse have generated considerable literature and take into consideration the same factors that are considered in playground falls to the surface when considering the load applied to the bone prior to fracture. Pierce et. al. (2003) found that softer surfaces result in less energy available for the injury, while harder surfaces are more efficient in transmitting energy to the body and that fracture morphology is a direct reflection of the

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[80] [80] ASTM F2223-03, Standard Guide for ASTM Standards on Playground Surfacing, ASTM, 2003, p2

[81] Ryan LM, Teach SJ, Searcy K, Singer A, Wood R, Wright JL, Chamberlain, JM, Epidemiology of Pediatric Forearm Fractures in Washington, DC, Journal of Trauma-Injury Infection & Critical Care, October 2010, pS200

[82] S. Laforest, Y Robitaille, D Lesage, D Droval, Surface characteristics, equipment height and the occurrence and severity of playground injuries, Injury Prevention 201; 7;35-40, p5

[83] S. Laforest, Y Robitaille, D Lesage, D Droval, Surface characteristics, equipment height and the occurrence and severity of playground injuries, Injury Prevention 201; 7;35-40, p1

[84] Sherker S, Ozanne-Smith J, Are current playground safety standards adequate for preventing arm fractures, MJA, June 2004, p564-565

[85] Sherker S, Ozanne-Smith J, Rechnitzer G, Grzebieta R, Out on a limb: risk factors for arm fractures in playground equipment falls, Injury Prevention, 2005, 120-124

[86] Fiissel D, Pattison G, Howard A, Severity of playground fractures: playground equipment versus standing fall heights, Injury Prevention, 2005, P338

degree and direction of forces and the ability of the tissue to resist those forces.[87] This area of research for long bone injury is very similar to the automobile information relating to the head injury and is a valid source of information, data and performance requirements that could be applied to the playground injury.

The conclusion that can be made from the studies on long bone fractures, primarily in playgrounds, is that a reduction of both the Gmax to below 105 to 110g and the HIC to below 570 for children structures under 5 and below 700 for play structures intended for 5-12 year olds would have a beneficial outcome on the incidence of long bone injuries. However, these changes would not eliminate this type of injury, but result in a measureable reduction with added benefit towards head.

Impact Velocity and Free Fall Height

For all of the twenty-five NFL players, the average impact velocity was 9.3 ± 1.9 m/sec[88] or the equivalent of a 4.4m (14.4') free-fall drop. The average velocity at impact for the three concussions sustained as "head to surface" without prior player impact was 6.8 m/sec[89] or equivalent to a 2.36M (7.75') free-fall drop. The average Gmax for the twenty-five helmeted football players was 98 g's and for the head to turf players was 123g's. The 200g threshold that the unprotected child is currently required to endure on a playground surfaces when compared to football players is unreasonable. It must be remembered that when a child falls from a 9' slide deck, that child would be travelling at 7.3m/sec (24 ft/sec) or 16.4mph from the deck height and 8.5m/sec (27.7ft/sec) or 18.61 mph at the time they hit the surface. The only protection at that point is the ability of the surface to absorb the impact to the Gmax of <105 and HIC of less than 700.

Discussion around a new threshold based on AIS ≥4 will have to include a consensus decision as to whether a concussion would be considered as a "debilitating injury" and therefore affect the determination of the threshold for ASTM F1292 and the CPSC document #325. An alternative would be a recommendation to users and caregivers of the user of the playground, as to what impact values could result in a concussion and that appropriate diagnosis and treatment processes can be performed.

Considerations for Implementation of Playground Surfacing Performance for ASTM F1292 and the CPSC Handbook

There are a number of factors that have come to light in relation to the ASTM F1292 and CPSC Public Playground Safety Handbook. The primary concern is the effectiveness of the current Gmax and HIC values and what the goals for any new threshold for compliance to the standard should become. Although most of the impact intervals related to playground surfaces are generally less than 10ms as in the automotive studies, there are some surfaces designed for very low Gmax and HIC at above 10' (3m) that have demonstrated intervals in the 16 to 18ms and there must be a determination if the HIC calculation shall be constrained to 15ms for HIC_{15}. Additionally it might be time to consider a different HIC_{15} threshold for playground surfacing under play structures intended of children under 3 based in the HIC_{15} threshold for the 3 year old dummy of 570 and the HIC_{15} value for the 6 year old dummy being

[87] Pierce MC, Bertocci GE, Vogeley E, Moreland MS, Evaluating long bone fractures in children: a biomechanical approach in illustrative case, Child Abuse & Neglect, January 2003, p508 & p520
[88] Viano, DC, Casson IR, Pellman EJ, Concussion in Professional Football: Biomechanics of the Struck Player – Part 14, Neurosurgery, August 2007, p318
[89] Viano, DC, Casson IR, Pellman EJ, Concussion in Professional Football: Biomechanics of the Struck Player – Part 14, Neurosurgery, August 2007, p319

700. For the Gmax there is injury data to support a reduction as a minimum to 125g. The separation of impact attenuation values by age group would be consistent with both ASTM F1487 and the CPSC as age and anthropological differences are use as rationale factors that determine technical requirements for play structures aimed at each group.

Implications for playgrounds, owner/operators, manufactures and installers

Currently there are a number of laws and mandates in Canada and the United States that reference compliance to ASTM F1292 for the installed playground surface. Many of these such as the 2010 American with Disabilities Act Accessibility Standards reference the ASTM F1292 by specific revision date[90] and this would not affect current playgrounds and a surface complying with the new thresholds would automatically comply with the mandated document. This would be the same in Canada, where in 2007, the CSA Z614 raised the fall height for play structures with platforms to the height above the platform of the minimum barrier[91] and specifically stated that the surface testing was to take place to the standard of the day it was installed[92].

It is important to review the financial impact and availability of products related to the acceptance of the recommended changes in Gmax and HIC. Currently products such as engineered wood fibre, loose rubber nuggets, mulch and crumb, some specific sands and gravels when installed and maintained to their appropriate depth will at not or very little additional cost meet the new requirements. A review of many of the websites for these types of products indicate significantly better performance than the existing thresholds from heights that are significantly higher than the fall heights of most playground equipment at 8' to 10' (2.4 to 3M). As a result the change should not be an economic burden on the suppliers of these products or their purchasers. As always, there will continue to be a requirement to maintain the depth, cleanliness and performance of the surface to the standard over the life of the playground. For owner/operators currently budgeting and providing this maintenance, there will not be a new financial impact on their facilities. It is however recognized that the reality of playgrounds is that playground surfacing is not installed or maintained to an adequate level. This was confirmed by the Consumer Federation of America in 2002 when 75% of playgrounds reviewed were not adequate and this was an improvement over their review in 2000 when it was found that 80% were inadequate.[93]

The greatest problem for products with relation to the new thresholds will be the unitary or synthetic surfacing systems that have traditionally been used in playgrounds. A review of numerous surfacing manufacturers' websites for products supplied around the world, these products are manufactured and "rated" to provide a specific critical height, which is then closely matched to the maximum fall height of the play structures. Most manufacturer/supplier/installers offer a variety to critical height products to be matched to fall heights as lower and higher play structures are installed. There is an increasing cost to the end user of these products directly related to increase in thickness of the product and critical height. As a result the cost of synthetic surfacing under a playground will be affected by the required critical height of the surfacing. Although each surface system will have variations, the effect would be to take a surface with a current F1292 critical height and match it to a 30 to 40% lower fall height.

[90] U.S. Department of Justice, 2010 ADA Standards, September 15, 2010, page 10
[91] CSA Z614-07, Children's Playspace and Equipment, Canadian Standards Association, 2007, p48
[92] CSA Z614-07, Children's Playspace and Equipment, Canadian Standards Association, 2007, p15
[93] Weintraub R, Cassady A, Playing It Safe: The Sixth Nationwide Safety Survey of Public Playgrounds, the Consumer Association of America, June 2002, P1

Synthetics in playgrounds have been either rubber tiles or poured-in-place surfaces. The tiles or mats are the combination of rubber granules or crumb bonded with a polyurethane binder in ambient conditions or inside a mould and pressed. These mats typically appear to be a sheet of rubber over legs or stanchions and the impact attenuation is based on the ability of the upper rubber sheet to compress and flex and the legs to compress as force is applied. Tiles are almost always manufactured in a factory and transported to the playground for installation. Poured-in-place on the other hand involves the mixing of the rubber crumb and/or shreds with a polyurethane binder and placing it in multiple layers in the playground. Detailed information with regard to the poured-in-place surfacing can be found in ASTM F2479, Standard Guide for Specification, Purchase, Installation, and Maintenance of Poured-In-Place Playground Surfacing.[94] Generally, the impact attenuation of these surfaces is achieved through the ability of the wear course or top mat, to indent and bend and the ability of the cushion layer to allow the upper layer to penetrate under load.

As with everything, innovation has brought new synthetic surface systems to the playground. Many of these have been developed to provide critical heights in excess of the traditional playground fall heights. Some of these systems are combinations of artificial turf, rubber matting, and PVC or other sheet type materials that can be applied in multiple layers. Since these systems have been designed for both long term compliance to ASMF1292 and the ADA standard, it is likely that improved critical height technology has been built into the new design. An example of this would the Liberty Tire SMARTE product that is generally 4" in thickness with the results for the ASTMS F1292 laboratory testing shown in table 4.

Product	Drop height	Gmax	HIC
LTR Smarte	8' (2.4M)	55	226
LTR Smarte	12' (3.65M)	79	372
LTR Smarte	14' (4.25M)	94	517
LTR Smarte	15' (4.57M)	98	625
LRT Smarte	17' (5.2M)	97	672

Table 4. Liberty Tire Recycling SMARTE ASTM F1292 test result.[95]

Some existing materials and new surface products on the market have a demonstrated capability of meeting the new performance requirements. Clearly the proposed changes to ASTM F1292 for Gmax and HIC can only benefit the reduction of risk of severe injuries due to falls to the playground, thereby improving opportunities for play while minimizing risk of injury. When considering the cost to the child of a life altering injury or the cost of rehabilitation or the cost to an already over-burdened healthcare system, the benefits resulting from making these changes should not be overlooked. These changes will also have the effect of allowing designers to design while truly protecting children from unforeseen fall hazards in the playground environment and allowing children to experience greater challenges in the playground.

Acknowledgements

[94] ASTM, ASTM F2479-07, Standard Guide for Specification, Purchase, Installation and Maintenance of Poured-In-Place Playground Surfacing, 2007

[95] IPEMA Surfacing Material Reports F1202 TUV SUD America Inc., reports QI1101998, QI1008015, QI1005055

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ASTM F1487, Standard Consumer Safety Performance Specification for Playground Equipment for Public Use, ASTM International, West Conshohocken, PA, USA, 2001, 2005, 2007

ASTM F1936, Standard Specification for Impact Attenuation of Turf Playing Systems as Measured in the Field, ASTM International, West Conshohocken, PA, USA, 1998, 2007, 2010

ASTM F1951, Standard Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment, ASTM International, West Conshohocken, PA, USA, 1999

ASTM F2223, Standard Guide for ASTM Standards on Playground Surfacing, ASTM International, West Conshohocken, PA, USA, 2003, 2009, 2010

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