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UNITED STATES GOVERNMENT

MEMORANDUM

U.S. CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, D.C. 20207

RECEIVED-OFFICE OF THE SECRETARY

APR 24 1990

TO : The Commission
Through: Sadye E. Dunn, Secretary
Through: Susan Birenbaum, Acting General Counsel
Through: Thomas W. Murr, Jr., Acting Executive Director
Through: Douglas L. Noble, Director
Office of Program Management and Budget
Through: David W. Thome, Program Manager
Emerging Hazards/Vulnerable Populations, EXPB

FROM : Elaine A. Tyrrell, Project Manager
Vulnerable Populations, EXPB

SUBJECT: Playground Equipment Handbook Project - Transmittal of Final Technical Report from COMSIS, Inc.

This memorandum is to advise the Commission of the completion and availability of a final technical report prepared under contract by COMSIS, Inc. entitled, "Development of Human Factors Criteria for Playground Equipment". (The report is available for review by the Commissioners and their staff in the Office of the Secretary). This report is the basis for a second document developed under the same contract which contains the technical text to be used in the update and expansion of the original CPSC **Handbook for Public Playground Safety**, Volumes I and II.

The purpose of the technical report was to identify and recommend criteria for the types and sizes of playground equipment best suited to the capabilities and limitations of children at various developmental levels. The information used to develop these criteria included: published playground equipment literature, safety standards and guidelines, child developmental literature and anthropometrics, accident/injury studies, indepth investigations, playground equipment catalogs and an observational study conducted by COMSIS of children on playground equipment.

This technical report provides an extensive discussion of the issues, background, and findings related to safety-related problems for public playground equipment as well as the rationale for each recommendation. This report also provides the information necessary to revise, update, and expand the existing handbooks to include equipment safety consideration for preschoolers, ages 2-5 (existing handbooks only cover ages 5-12), and to reflect the changes in equipment design and construction materials that have occurred since the late 1970's.

The COMSIS report discusses playground surfacing which is also the subject of one of the Commission's FY 1990 Focus Projects. The surfacing section in the COMSIS report provides general guidelines and recommendations for surfacing which will minimize serious injuries due to falls. The purpose of the Focus

NOTE: This document has not been reviewed or accepted by the Commission.
Initial rlv Date 4/23/90

Project is to publish and distribute a Technical Fact Sheet on the impact attenuation (energy absorbing) performance of specific types of loose fill playground surfacing materials (i.e., pea gravel, sand, mulch and bark chips). The technical work for this Fact Sheet will be completed by the end of April and the Fact Sheet will be prepared for distribution to targeted user groups by the end of the fiscal year. The engineering report, which is being prepared for the Focus Project, is currently being circulated for clearance and will be transmitted to the Commission shortly. The report will then be available to the public upon request.

This technical report will be shared with the ASTM Task Group F15.29, Playground Equipment for Public Use, for their review and comment prior to the publication of the revised handbook, which is currently scheduled for early 1991.

This report has been cleared pursuant Section 6(b) Consumer Product Safety Act and will be released to the public upon request.

UNITED STATES GOVERNMENT

MEMORANDUM

U.S. CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, D.C. 20207

MAR 26 1990

TO : Elaine A. Tyrrell, Project Manager, EXPB
Through: Dr. Robert D. Verhalen, AED, Epidemiology
Through: Dr. Robert M. Carroll, Director, EPHF

FROM : Marie L. Bellegarde, EPHF MLB

SUBJECT: Playground Equipment Project- Transmittal of Final Technical Reports from COMSIS, Inc.

This memo transmits the final technical report prepared under contract by COMSIS, Inc. entitled, "Development of Human Factors Criteria for Playground Equipment Safety", and a second document, "A Handbook for Public Playground Safety" which contains the technical text to be used for the update of the current CPSC playground handbooks.

DEVELOPMENT OF
HUMAN FACTORS CRITERIA
FOR PLAYGROUND EQUIPMENT SAFETY

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ACKNOWLEDGEMENT

The authors wish to acknowledge the invaluable support provided by individual staff members of the Consumer Product Safety Commission, who generously shared their time, expertise, and resources. In addition, numerous individuals with expertise concerning various aspects of playground equipment or design were contacted during the course of the study, and we thank them all for their valuable information and insights. A panel of outside experts reviewed draft versions of the report, and their careful review and thoughtful critiques strengthened the finished document. In her role as technical editor of the report, Susan Feller helped to make this lengthy document more cohesive. Finally, we would especially like to thank Marie Bellegarde, who served as CPSC's project officer for this contract. Her contributions and support throughout the project were important and deeply appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure

1. PURPOSE AND BACKGROUND

1. PURPOSE AND BACKGROUND

The playground is an important part of a child's world. It is a setting in which to have fun, to develop physical strength and coordination, to enhance cognitive and social skills, and to be challenged and gain confidence. It is also a place where a child may get hurt. Between 1982 and 1986, the total number of home and public playground equipment injuries that were treated in U.S. hospital emergency rooms averaged about 200,000 per year; approximately 30% of these injuries were sustained by children under the age of 5 (Nichols, 1988).

In 1981, the Consumer Product Safety Commission (CPSC) issued a two-volume publication entitled *A Handbook for Public Playground Safety*. The document provided an important set of guidelines promoting safer design and use of public playground equipment. This present report is intended to update and expand the Handbook. In addition to incorporating technical findings and equipment changes over the past decade, the project also provides the opportunity to give greater attention to age-related considerations in playground equipment design. Children under age 6 are at particular risk of serious injury, as indicated by accident data. Therefore, explicit consideration is given to equipment intended for use by preschool-age children (2 to 5 years old), as well as to equipment intended for school-age children (4 to 12 years old). Although there is some overlap in the age ranges of the intended users as selected for equipment design purposes, the recommendations developed in this report recognize the important differences between preschool-age and school-age children in terms of their physical capabilities, anthropometric measures, play patterns, and cognitive skills. Moreover, this overlap acknowledges that developmental maturation occurs through continuous rather than abrupt changes, that children's physical, cognitive, and social skills develop at different rates, and consequently that key developmental milestones are acheived at different times for different children.

The report deals with the development of equipment design and use guidelines for public playground safety. "Public" playground equipment refers to products intended for use in play areas of parks, schools, institutions, multiple family dwellings, resorts and recreational developments, and other areas of public use. It does not include amusement park equipment, sports equipment, or home playground equipment. The guidelines specifically address play areas containing public playground equipment, and not other areas of playgrounds or other possible public playground settings, such as garden settings, water settings, and staging areas.

The primary focus of this report is safety. Discussion of other important design considerations for playground equipment, such as play value, motor skill development, or cognitive, social, and emotional benefits is limited, and relates to their impact on safety. The guidelines are intended to help identify what constitutes a safe piece of equipment; however, a safe design is not necessarily a "good" design in all aspects. The report and Handbook also do not address requirements for children with special needs, including those with physical disabilities; although this is an important concern, it is beyond the general focus on safety in this work.

In developing safety recommendations, the difference between "challenge" and "risk" must be kept in mind (see Section 5.3.1). 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. It is recognized that an ideal playground environment will allow children to progressively develop and test their skills; some chance of failure is inevitable, and even desirable. When developing safety criteria, the opportunity for challenge should not be removed from equipment. Challenges should be reasonable given age-related physical abilities, ones that children can perceive and accept. Risk, however, presents the potential for serious injury as a consequence of failure. To minimize risk, unintended and unnecessary hazards should be eliminated.

This report is the basis for a second document, developed under the same contract, which contains the technical text to be used in the update and expansion of the original CPSC guidelines under the same title, *A Handbook for Public Playground Safety*. This report is very detailed and is intended to serve a varied audience of guideline users: equipment manufacturers, parks and playgrounds personnel, school officials, installers, equipment purchasers, and concerned members of the general public such as parents or school groups. The revised Handbook will be largely limited to a presentation of the actual guidelines. The report, however, provides a full discussion of the issues, background, and findings related to each safety problem, as well as a description of the rationale underlying each recommendation. This sort of detail will prove useful in a number of ways. It gives a foundation for the evaluation of the recommendations and the strength of their technical basis. It can help when adapting the guidelines to new equipment or circumstances not explicitly treated, or provide a basis for considering exceptions. It can aid equipment designers in addressing issues of concern. It can also provide a technical resource for use by any groups developing standards or guidelines which may go beyond the revised Handbook in terms of scope or detail. Finally, it can aid in any future updates of the Handbook. In developing the report, the project team was frequently frustrated because when evaluating the earlier Handbook and numerous other standards and guidelines, the technical bases and rationale for recommendations were not always made explicit.

The following section presents a description of the methods and resources used in this project. Following this is a brief overview of the major findings of playground injury studies, along with a discussion of some of the limitations of these studies. Last in the introductory sections is an overview of the major developmental considerations that influence the design and use of playground equipment; these include physical abilities, cognitive, social, and emotional skills, and play patterns.

The major portion of this report consists of a detailed analysis of playground equipment design considerations. This is structured around the contents of the original CPSC Volumes I and II of *A Handbook for Public Playground Safety*, but goes beyond them in many cases. The analyses and recommendations will cover general features of equipment, such as general hazards or layout, and specific types of equipment, such as slides or swings.

2. METHODS

A variety of resources and methods were used to analyze the current guidelines and to develop new ones. Among the approaches used were the following:

Review of Technical Literature

An extensive technical literature search was conducted in late 1988 and early 1989. This search included both automated keyword searches of major computerized literature databases and manual searches of key journals and library collections. The search focused on the period from 1977 onward, since the earlier literature was reviewed as part of CPSC's efforts in developing the original Handbook. The databases searched included scientific and engineering (e.g., SciSearch, NTIS), behavioral and social sciences (e.g., PsychInfo, Eric), medical (e.g., Medline), product-related (e.g., Thomas New Industrial Products), and physical education/sports/recreation (e.g., Sport Database). Manual library searches took advantage of some of the special resources in the Washington, DC, area, including specialized collections of the National Library of Medicine, the National Bureau of Standards, the University of Maryland, and the Library of Congress. The references identified through the automated searches and library searches were further supplemented by sources identified through expert contacts, and from materials collected by CPSC in the course of its ongoing work.

Review of Standards and Guidelines

A variety of documents related to playground equipment design specifications were reviewed and compared. These included both formal standards (some still in draft form) and published recommendations without any "official" status, from foreign as well as domestic sources. The scope and detail of these standards and guidelines varied greatly.

The major standards reviewed included those from Australia, Canada, Great Britain, Germany, and New Zealand, as well as draft standards from Seattle, Washington; full citations of all standards reviewed are in the References section (see Section 7).

In addition to the standards, other references especially prominent among the various guidelines were the *Play For All Guidelines* (Moore, Goltsman, and Iacofano, 1987) and *The Early Childhood Playground: An Outdoor Classroom* (Esbensen, 1987), and recommendations made by Frost (1986a; 1986b; 1986c; 1988; U. of Texas, 1989, unpublished manuscript; Frost and Campbell, 1978; Frost and Henniger, 1979; Frost and Wortham, 1988) in several technical articles.

Review of Developmental Literature and Anthropometrics

Major sources in developmental psychology, early childhood education, and physical development were reviewed and the key findings summarized. The major points are discussed in detail in Section 4 (Developmental Considerations). The results of this review have broad implications for many aspects of playground equipment design and use. In developing formal design recommendations, it is critical to have adequate anthropometric (body dimension) data for children of various ages. There are not extensive published resources in this area, but four documents were relied on extensively throughout this project. These major child anthropometry references were: *Physical Characteristics of Children as Related to Death and Injury for Consumer Product Safety Design* (Snyder, Spencer, Owings, and Schneider, 1975); *Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design* (Snyder, Schneider, Owings, Reynolds, Golomb, and Schork, 1977); *Gripping Strength Measurements of Children for Product Safety Design* (Owings, Norcutt, Snyder, Golomb, and Lloyd, 1977); and *Size and Shape of the Head and Neck from Birth to Four Years* (Schneider, Lehman, Pflug, and Owings, 1986).

Review of Accident/Injury Studies

A variety of formal accident studies were collected and reviewed. These varied widely in size and scope. Some focused specifically on playgrounds, while others were more broadly concerned with childhood injuries; some included consumer playground products as well as public playgrounds, and some were restricted only to school settings. The sources included both U.S. and foreign studies. Some were based directly on hospital injury data, others on survey methods. While varied and often difficult to compare directly, the accident studies provided a valuable source of information.

The major accident/injury studies and their characteristics will be discussed in greater detail in Section 3 (Injury Data Overview).

Analysis of In-Depth Accident Investigations

CPSC collected in-depth accident investigation reports for playground equipment-related injuries occurring in 1988 as part of a formal epidemiological study of playground injuries. These were based on phone interviews and/or on-site investigations. A subsample of 189 of these investigations was provided to COMSIS for detailed analysis. The incidents included those occurring in schools, parks, and other public settings, as well as on home playground equipment. The ages of the victims ranged from 2 to 14 years old. All types of playground equipment and injuries were included.

The analysis of these accident cases is referred to as the "detailed incident analysis" whenever it is discussed in the body of this report. This serves to distinguish the analysis from other quantitative accident and injury studies, including CPSC's epidemiological study. It emphasizes the fact that the purpose of the study of these cases was to provide a detailed, qualitative understanding of the dynamics of typical accident scenarios, and not to provide a statistical description of the overall injury experience (see Section 3 for further discussion).

A specially developed coding form was used in the analysis of the accident cases, and is included as Appendix A of this report. The form consists of four general sections, addressing characteristics of the victim, the product, the environment, and the incident. The coding places particular emphasis on the behavioral and human factors engineering aspects of the incidents.

Contact with Experts

Experts in playground safety or related areas were contacted, generally by phone. Their areas of expertise included park safety and maintenance; architecture, landscape architecture, and environmental psychology; early childhood education; developmental psychology; human factors design and engineering; physical education and sports; child safety advocacy; pediatric medicine; recreation management services; stairway safety, falls; and government research.

The contacts with the expert community ranged from general discussions of major playground safety issues to very specific considerations of particular design issues. The expert contacts also served as important means for identifying recently published, ongoing, or unpublished technical sources.

Observational Study

An informal observational study was conducted as part of the project to supplement the published findings on the behavior and play patterns of children on playground equipment. Children were videotaped as they played on equipment in a variety of settings, involving a range of equipment types. The majority of observations were directed at preschool-age children, but children of all ages were included. Children were recorded playing in groups and individually. Settings included tot lots, daycare and preschool facilities, parks, and playgrounds. Both traditional and newer types of equipment were included. Sites were all in the greater Washington, DC, area, and included Montgomery County, Maryland, the District of Columbia, and northern Virginia.

In videotaping, the camera person assumed as inconspicuous a position as possible, although no attempt was made at concealment. It was clear from the videotapes that the children (particularly the preschoolers) were unconcerned with the camera.

The contents of the videotapes were catalogued by the type of equipment used, the type of setting, and the approximate age of the children. Unusual incidents or points of special interest were also noted. The cataloging made the videotapes a readily usable resource as each type of equipment or activity was being analyzed later in the project.

The observational study actually consisted of two phases. The first phase, conducted in fall, 1988, provided a broad and general sample of play on a wide variety of equipment. It served as a general resource for much of the later analysis. The second phase, conducted during the summer of 1989, more specifically targeted certain scenarios that had emerged as of particular concern in the course of the analytic work. The Phase 2 observations focused on three primary issues:

1. Modes of access. Children were observed using a wide range of access modes, such as steps, ladders, and flexible climbing devices (e.g., net climbers, tire climbers). The video recordings included shots of children of various ages, individually and in groups, as they attempted to access equipment, and also included more close-up shots of leg movements and foot positioning.

2. Transitions to platforms. One of the important danger points, and a key area for design considerations, is the transition area where children move from a climbing position on an access device to some other posture (standing, sitting) at the platform to which the access device leads. Children were videotaped making this transition on a variety of access modes and equipment types.

3. Climbing equipment. Children of various ages were videotaped at play on a range of climbing equipment. These observations were intended to broaden the range of settings for climbing equipment beyond that collected in Phase 1.

<u>Review of Equipment Catalogs</u>

Playground equipment catalogs from a wide range of major manufacturers were reviewed and used as frequent reference sources through the course of the work. The catalogs provided information on equipment types, common designs and features, dimensions and specifications, layout, materials, hazards, and modes of use.

3. INJURY DATA OVERVIEW

3. INJURY DATA OVERVIEW

3.1 LIMITATIONS OF PLAYGROUND INJURY DATA
3.1.1 Availability of equipment
3.1.2 Frequency of use
3.1.3 Age-related differences in injury frequency
3.1.4 Differences among injury data sources

3.2 AVAILABLE INJURY DATA SOURCES
3.2.1 1979 Hazard Analysis
3.2.2 1982-87 NEISS data
3.2.3 1988 NEISS data
3.2.4 Other data sources

3.3 SUMMARY OF INJURY DATA
3.3.1 Estimates of total playground equipment-related accidents and injuries
3.3.2 Equipment type by age
3.3.3 Mode of injury by age
3.3.4 Injury pattern by equipment type and age

3.1 LIMITATIONS OF PLAYGROUND INJURY DATA

Available accident data sources should be interpreted cautiously, in part because of their methodological and sampling limitations, but also because variables related to children's exposure to equipment make it difficult to draw conclusions about injury frequencies. A higher frequency of injury for one type of equipment does not necessarily mean that it is inherently more dangerous than another type of equipment. Frequency of injury also reflects other factors such as the relative availability and frequency of use of different equipment types. Unfortunately, few studies provide information on children's level of use and exposure to different equipment types, or on how these factors may differ for older and younger users. Since studies of equipment-related injuries sample different types of play areas (home play area vs. school or public playground) in different countries at different times and apply different methodologies, the comparison of injury data across studies has additional limitations. The following issues should be considered when interpreting and comparing available data on playground equipment-related injuries.

3.1.1 Availability of equipment

To determine whether the frequency of injury associated with a certain type of equipment is disproportionately high, it is important to know the proportion of the total available equipment that this type represented during the data collection period. Availability of equipment can vary with the type of play area (home play area vs. school or public playground), the region sampled, and with the time period covered by the study. For example, climbing equipment is more likely to be found on school and public playgrounds than in home play areas, and climbers may be more common in some countries than in others.

3.1.2 Frequency of use

The proportion of all equipment-related accidents associated with one type of equipment is likely to be higher if that equipment is used more frequently than other types. One factor that influences frequency of use is the total number of children who can play on the equipment at one time. Because some climber designs can accommodate more users simultaneously than other kinds of equipment, they are likely to show a higher frequency of injury per piece of equipment. Moreover, the multi-use nature of climbing equipment may increase the potential for horseplay and misuse of equipment, particularly when equipment is overcrowded, thus contributing to a higher incidence of injury relative to other equipment types.

3.1.3 Age-related differences in injury frequency

The caveats observed when evaluating whether one type of equipment is more hazardous than another should also be applied to interpreting age-related differences in frequency of injury. When evaluating whether younger children are at greater risk than older children for injuries associated with a particular type of equipment, one should consider differences between the two age groups in their exposure to that equipment type. Younger and older children may have different exposures to certain equipment, depending on the types of play areas that they most frequently use and the types of equipment they prefer. For example, climbers are less likely to be used by younger children, since climbers are less available in home play areas as compared to public and school playgrounds, and younger children on average have more frequent access to home play equipment than to public or school equipment (King and Ball, 1989). Another factor that may contribute to lower exposure of younger children to climbers is that climbers require more advanced developmental skills than other equipment types, and so may be less popular with the younger age group. These age-related differences in exposure to climbing equipment have been used to explain the relatively low proportion of all climber-related injuries sustained by younger children (0- to 4-year-olds) (King and Ball, 1989).

To determine whether the number of equipment-related injuries is disproportionately high or low among younger children, it is also important to consider the age distribution in the population at the time the injury data were collected. In their discussion of the 1982-86 National Electronic Injury Surveillance System (NEISS) injury data, King and Ball (1989) concluded that slide injuries were disproportionately high among younger children, because even though 0- to 4-year-olds accounted for less than one half (45%) of all slide-related injuries, there were one-half as many 0- to 4-year-olds as 5-to 14-year-olds in the total U.S. population during the period covered by the NEISS data. This strategy is justified only insofar as sample data accurately reflect the incidence of injuries in the population. The NEISS injury data satisfy this criterion because they are national estimates based on weighted data from a national sample of injuries. However, other studies discussed in this report are not based on nationally representative samples, and so any age bias in their reporting systems would tend to invalidate comparisons between age-related frequencies of injury in the sample and the age distribution in the population.

3.1.4 Differences among injury data sources

Recommendations presented in this report have been guided in part by a consideration of available injury data collected in the U.S., Canada, Great Britain, Holland, Denmark, New Zealand, and Australia. Differences among these studies in location of incidents (public playground vs. home play area), methodology, sampling, time period covered, equipment characteristics, and classification of injury severity make comparisons across studies problematic, and limit the ability to generalize results to the population of playground injuries. These critical differences are discussed below.

Location of incidents. Studies differ in whether they include incidents that occur on public playgrounds, school playgrounds, or in home play areas. Some studies sample only one type of location while others combine injury data from play areas intended for public use with those from home play areas. Location of incident affects not only the distribution of different equipment types and the age distribution of children, but also the design characteristics, method of installation, and durability of equipment. Therefore, comparisons of injury data collected from different types of locations are not valid.

Methodology. Sources of data range from hospital emergency room or admission records to public school accident reports and survey data collected from parents of accident victims. Therefore, the definition of an "accident" varies considerably across studies, and includes those incidents resulting in hospital admission, hospital emergency room treatment, or a visit to a doctor, and more idiosyncratic criteria, such as any accident resulting in a pupil being absent from class for more than one half hour (Inner London Education Authority, 1988, reported in King and Ball, 1989). The source of injury data can bias the distribution of superficial and serious injuries: hospital emergency room records are more likely to show a higher percentage of serious injuries than surveys in which parents provide data on playground accidents. Moreover, when studies are limited to injuries that were serious enough to require hospital admission, injury data are not comparable to those based on emergency room records.

Accident surveys that rely on self-completion questionnaires are subject to inaccuracies and incomplete answers, particularly with regard to the causes and locations of accidents (King and Ball, 1989). When questionnaires are administered to parents of victims, those who choose to respond are not likely to comprise a representative sample; moreover, information about the severity of injury is not comparable to the more precise data provided by medical personnel in studies based on hospital records.

Sampling. Databases on playground equipment-related injuries that have been set up in the U.S., Australia, and Canada reflect efforts to use a nationally representative sample of hospitals. As noted above, only NEISS currently provides national estimates of playground equipment-related injuries based on weighted data from a nationally representative group of hospital emergency rooms. According to King and Ball (1989), Australia's National Injury Surveillance and Prevention Project (NISPP) covers equipment-related injuries recorded by a nationally representative group of hospital accident and emergency departments, but the data are not intended to be used as national estimates of playground injuries. NISPP data (1988) presented by King and Ball consist of sample frequencies of injury and not national estimates. Although hospitals that participate in the Canadian Accident Injury Reporting and Evaluation system (CAIRE) were chosen to be geographically representative, the current samples are not considered large enough to comprise a statistically valid national database (King and Ball, 1989). With the exception of these three injury data sources, all other studies considered in this report are subject to sampling biases related to the location of incidents, such as the age distribution of victims (which affects the pattern of injury), types of play areas (which are correlated with distribution of equipment types and age of victims), and weather conditions (which influence level of use). Studies that are limited to information collected from one or two hospital accident and emergency rooms are particularly prone to sampling bias.

Time period covered by study. Injury data based on hospital emergency room records have been collected over time periods ranging from 4 weeks (e.g., Oliver, McFarlane, Cant, Bodie, and Lawson, 1981) to 4 years (e.g, CAIRE 1982-86 data and NEISS 1982-86 data, reported in King and Ball, 1989). Short-term studies that have not taken seasonal variations into account are likely to produce biased results, since playground accidents occur more frequently in the summer, and some types of equipment (e.g., swings) are frequently taken down in the winter and put up again in the spring or early summer (Rutherford, 1979).

In addition, the results of older studies may not accurately reflect current patterns of injury, because the subsequent adoption of national standards may have led to basic modifications in equipment design and playground layout, and the relative availability of different equipment types may have changed (King and Ball, 1989).

Equipment characteristics. Within any given study, all pieces of equipment that are classified together are not necessarily comparable in design; for example, climbing equipment can be a heterogeneous category that includes upper body devices (e.g., chinning bars and overhead horizontal ladders), sliding poles, balance beams, etc. (e.g., Bruya and Langendorfer, 1988). Moreover, the characteristics of equipment in the same category can vary considerably from study to study, particularly if studies were conducted in different countries. For example, King and Ball (1989) found that the height of equipment, especially of climbers, was higher in Australia and New Zealand than in other countries, and that trampolines (which were often classified with "other equipment") were a prominent cause of serious accidents in Australia and New Zealand, but were not as popular in other countries. Because studies often do not fully define each category of equipment, comparisons of injury data by equipment type across studies should be regarded with caution.

Injury severity. When comparing the patterns of injury associated with different types of equipment, 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). For example, although swings have been associated with high frequencies of head injury relative to other equipment types, slides have accounted for the highest frequencies of serious head injury, including concussion, internal head injury, and skull fracture (King and Ball, 1989). However, severity of injury is not always defined precisely, and is not defined consistently across studies: "serious" head injury may denote head injury associated with loss of consciousness (e.g., Pitt, 1988, reported in King and Ball, 1989), skull fracture and/or 3 or more days absence from school (e.g., ILEA study, reported in King and Ball, 1989), or skull fracture, concussion, and/or internal head injury (e.g., King and Ball, 1989).

In this report, severe injuries are generally defined as fractures; severe head injuries also include skull fracture, concussion, and internal head injury. Superficial injuries are generally defined as contusions and lacerations. This classification of injury severity is consistent with analyses presented by King and Ball (1989).

3.2 AVAILABLE INJURY DATA SOURCES

The following served as primary data sources for this report: the 1979 Hazard Analysis based in part on a 1978 NEISS Special Study (Rutherford, 1979); unpublished NEISS data collected from 1982 to 1987 (reported in King and Ball, 1989); and, unpublished Canadian CAIRE data collected from 1982 to 1986 (reported in King and Ball, 1989). King and Ball's (1989) comprehensive review of playground injury data, which included some previously unpublished data, was used as the primary source for other results cited in this report. In-depth investigations of equipment-related injuries collected in 1988 as part of a CPSC special study provided the basis for a detailed analysis of common injury scenarios and patterns of use for different types of equipment. Brief descriptions of these data sources are presented below.

3.2.1 1979 Hazard Analysis

Rutherford (1979) based his Hazard Analysis on four sources: the 1978 NEISS Special Study, normal NEISS surveillance data, in-depth investigations of selected cases from the NEISS Special Study, and death certificates from the CPSC death certificate database covering the period between 1973 and 1977. What distinguishes the Special Study data from normal NEISS data is that, in addition to the usual information collected through NEISS (e.g., age and sex of patient, injury diagnosis, body part affected, product involved), more detailed information was obtained, including the type of equipment involved, the location of equipment (e.g., home play area vs. public playground), and the mode of injury (e.g., fall from equipment vs. impact with moving equipment). Rutherford's analysis of these data focused on injuries associated with public playground equipment.

3.2.2 1982-87 NEISS data

The CPSC supplied King and Ball (1989) with previously unpublished NEISS injury data covering the period from 1982 to 1987. Data from 1982 to 1986 provided national estimates of injuries by equipment type and age of child; more detailed analyses of data from 1985-86 and 1987 provided injury distributions by part of body affected, equipment type, and age. A further breakdown of data for 1987 showed the type of injury (e.g., laceration, contusion, fracture) associated with each body part. There are two important distinctions between the NEISS data estimated for 1982-87 and those estimated for the 1978 Special Study: 1) the more recent NEISS data do not distinguish between injuries sustained on both home and public playground equipment, whereas Rutherford's report addressed public playground injuries; and 2) the NEISS coding system was modified prior to collection of the more recent data. Therefore, the 1978 data and the more recent data are not strictly comparable (Nichols, 1988).

3.2.3 1988 NEISS data

The CPSC is currently engaged in a special study on playground equipment injuries, based on 1988 NEISS data. Two analyses of these data are cited in this report, and should be distinct. One analysis is a formal epidemiological study being conducted by the CPSC. The second analysis was conducted as part of the present project; it provided a detailed analysis of injury scenarios and the roles of various behavioral, environmental, and equipment factors. To distinguish the two analyses of the 1988 NEISS data, they are referred to as "the epidemiological study" and "the detailed incident analysis."

The CPSC epidemiological study employs careful sampling and formal statistical methods to project national estimates from the NEISS accident sample. It provides an update and expansion of the Rutherford Hazard Analysis published in 1979. The detailed incident analysis was based on an independent coding of 189 in-depth investigations collected as part of the CPSC epidemiological study. The purpose of the detailed incident analysis was to identify common injury scenarios and patterns of use for each type of playground equipment, with particular attention to age-related injury and use patterns. Its function was to help interpret the accident experience and the implications for product design. Although there is some overlap, the epidemiological study and the detailed incident analysis code different variables. In contrast to the epidemiological study, the detailed incident analysis did not attempt to provide accurate national estimates based on projections from the sample. Therefore, the relative frequencies of variables may not accurately reflect the true incidence of these variables in the population, and it would not be appropriate to compare the findings to the weighted estimates of the epidemiological study.

The coding form used to generate the database for the detailed incident analysis and the contents of the database are presented in Appendix 8.1 and Appendix 8.2, respectively. Cross-tabulations of selected variables are presented in Appendix 8.3.

3.2.4 Other data sources

Table 3 - 1 summarizes the basic characteristics of other studies cited in this report, including their methodology and sample, and the time period during which data were collected. The studies are organized by their country of origin.

3.3 SUMMARY OF INJURY DATA

This section presents an overview of injuries as a function of equipment type, mode of injury, and predominant pattern of injury, with breakdowns by age; more detailed discussion of injury data for each equipment type is found in Sections 5.7.1.2, 5.7.2.2, 5.7.3.2, 5.7.4.2, 5.7.5.2, 5.7.6.2. Since the findings of the CPSC's epidemiological study are not yet available, summary data on the percentages of all injuries associated with each equipment type and mode of injury are taken from the 1978 NEISS Special Study. Summary data on the predominant injury patterns associated with each equipment type are based on King and Ball's (1989) presentation of 1987 NEISS data and 1982-86 CAIRE data, both of which were previously unpublished.

3.3.1 Estimates of total playground equipment-related accidents and injuries

The 1978 NEISS Special Study indicated that about 93,000 injuries associated with public playground equipment were treated in U.S. hospital emergency rooms in 1977 (Rutherford, 1979). Based on 1982-86 NEISS data for injuries related to both home and public playground equipment, Nichols (1988) reported an average annual total of 200,000 injuries that received emergency room treatment. U.S. census estimates from 1988 show that there were about 17 to 18 million 0- to 4-year-olds and 34 million 5- to 14-year-olds in the total U.S. population between 1982 and 1986. Therefore, the average annual total of equipment-related injuries reported by Nichols corresponds to an emergency room treatment rate of approximately 390 out of every 100,000 children per year. This annual rate is lower than King and Ball's estimate that 500 children per 100,000 attend a hospital emergency room each year as a result of a playground equipment-related injury.

3.3.2 Equipment type by age

Injury statistics from the 1978 NEISS Special Study (Rutherford, 1979) are shown as a function of equipment type and age in Table 3 - 2A and Table 3 - 2B. It should be noted that percentages are based on total injuries sustained by 0- to 14-year-olds; injuries to children 15 years of age or older were excluded from the analysis.

Swing-related injuries accounted for the highest proportion of injuries among 0- to 4-year-olds; climber-related injuries accounted for the highest proportion of injuries among 5-to 14-year-olds (Rutherford, 1979). About one third of all swing-related injuries were sustained by younger children, whereas 9 out of 10 climber-related injuries were to older children.

3.3.3 Mode of injury by age

Table 3 - 3 presents a breakdown of injury statistics by mode of injury and age (Rutherford, 1979). 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. When falls that involved striking another part of the same equipment or another piece of

equipment are added to falls to the surface, the general category of falls represents almost two thirds (64%) of injuries to younger children and almost three quarters (73%) of injuries to older children.

3.3.4 Injury pattern by equipment type and age

The part of the body most commonly injured and the first and second most frequent patterns of injury are shown in Table 3 - 4 as a function of equipment type and age of the victim (King and Ball, 1989). Patterns of injury were defined by crossing location of injury (face, head, upper limb, lower limb, and trunk) and severity of injury (superficial vs. serious). Following King and Ball's (1989) classification of injury severity, fracture, concussion, and internal head injury were defined as serious injuries, while contusions and lacerations were defined as superficial injuries. When there were discrepancies between the 1987 NEISS data and the 1982-86 CAIRE data, both results were presented. For example, superficial head injuries were the second most common type of swing-related injury among younger children in the 1987 NEISS data, whereas the 1982-86 CAIRE data showed serious head injuries as the second most frequent type of swing-related injury for this age group.

For swings and climbers, the predominant body location of equipment-related injuries was different for younger children than for older children: injuries to the head and face were more frequent among 0- to 4-year-olds than among older children, while upper limb injuries were more common among 5- to 14-year-olds. The 1987 NEISS data supported this age-related pattern of results for slides; however, the 1982-86 CAIRE data showed the head and face rather than the upper limb as the predominant body location of slide-related injuries among older children. The most common injury pattern among younger children was superficial facial injury for all major types of equipment; by contrast, upper limb fracture was the most prevalent type of injury sustained by older children on swings, slides, and climbers. Upper limb fractures were more frequently associated with climbers than with other equipment types; trunk fractures were more frequently associated with seesaws.

Serious head injuries (including skull fracture, concussion, and internal head injury) accounted for a higher proportion of all slide-related injuries, compared to other equipment types. Serious head injuries were prevalent among younger children on swings, slides, and climbers; this finding may reflect differences in typical accident scenarios for younger and older children. 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 use their arms to break their fall and thereby protect their heads (King and Ball, 1989; Rutherford, 1979). By contrast, older children are better able to anticipate and avoid impact with moving swings, and to use their arms to break a fall. However, consistent with the predominance of upper limb fracture among older children on swings, slides, and climbers, older children probably reduce the risk of head injury due to a fall at the cost of increased risk of upper limb fractures.

TABLES

Table 3 - 1
Characteristics of Primary Accident Data Sources

Accident data source	Time Period	Methodology	Sample
U.S.			
Helsing, Rodgers, Mirabassi (1988)	1987-88	survey of parents of elementary school children	255 respondents
NEISS data:			
1978 NEISS Special Study (Rutherford, 1979)	Apr-May, 1978	hospital emergency room records	nationally representative sample of hospital emergency rooms
*(unpublished data, reported in King & Ball, 1989)	1982-87	hospital emergency room records	nationally representative sample of hospital emergency rooms
*(Morbidity and Mortality Weekly Report, 1988)	1983-87	hospital emergency room records	nationally representative sample of hospital emergency rooms; preschool-age children
Canada			
*CAIRE data (unpublished data, reported in King & Ball, 1989)	1982-86	hospital emergency room records; modified version of NEISS recording system	6 hospitals; 5685 equipment-related incidents

+Plus sign denotes studies cited in King & Ball (1989).
*Asterisk denotes studies known to include equipment-related injuries occurring in home play areas.

Table 3 - 1 (Continued)
Characteristics of Primary Accident Data Sources

Accident data source	Time Period	Methodology	Sample
Great Britain			
+Avery & Probert (1984)	1980-82	hospital emergency room records	2 hospitals
+Illingworth, Brennan, Jay, Al-Rawi, & Collick (1975)	(18 mo. duration)	hospital emergency room records	1 hospital; 200 equipment-related incidents
ILEA (unpublished data, reported in King & Ball, 1989)	1985-87	school playground accident reports: any incident resulting in more than one-half hour absence from class	1059 schools (preschool, primary, secondary)
Denmark			
+Christensen, Mikkelsen, Reich, & Krebs (1982)	1979-80	hospital emergency room records	466 equipment-related incidents
+Hansen & Kruse (1985)	Jan-Dec, 1982	hospital emergency room records	279 equipment-related incidents
Holland			
+PORS study (1987)	1985-86	hospital emergency room records; follow-up survey of parents of selected victims	not specified; 323 respondents (for all playground incidents)

+Plus sign denotes studies cited in King & Ball (1989).
*Asterisk denotes studies known to include equipment-related injuries occurring in home play areas.

Table 3 - 1 (Continued)
Characteristics of Primary Accident Data Sources

Accident data source	Time Period	Methodology	Sample
Australia			
+*Mater Hospital Study (Pitt, 1986)	1984-86	hospital emergency room records	1 hospital; 1088 equipment-related incidents
+*NISPP (1988)	1988	hospital emergency room records	13 hospitals (nationally representative sample)
+Oliver, McFarlane, Haigh, Cant, Bodie, & Lawson (1981)	Jun, Dec, 1978; Jun, Oct, 1979	hospital emergency room records	7 hospitals; 162 equipment-related incidents
+*Parry (1982)	1981-82	survey of parents	166 respondents
+Royal Alexandra Hospital (1981)	Jul-Oct, 1980	hospital emergency room records;	61 hospitals; 264 equipment-related incidents;
		follow-up study of selected cases	97 incidents in follow-up

+Plus sign denotes studies cited in King & Ball (1989).
*Asterisk denotes studies known to include equipment-related injuries occurring in home play areas.

Table 3 - 1 (Continued)
Characteristics of Primary Accident Data Sources

Accident data source	Time Period	Methodology	Sample
New Zealand			
Langley, Silva, & Williams (1981)	1978-80	school playground accident reports: any playground injuries requiring medical attention	83 primary schools
+*Chalmers & Langley (1988)	1984	hospital admission records for injuries due to falls from equipment	1035 incidents

+Plus sign denotes studies cited in King & Ball (1989).
*Asterisk denotes studies known to include equipment-related injuries occurring in home play areas.

Table 3 - 2A

Type of Equipment by Age of Victim*

	AGE OF VICTIM		
TYPE OF EQUIPMENT	0-4 Years	5-14 Years	0-14 Years
Climbers	31%	57%	53%
Swings	50%	18%	24%
Slides	14%	10%	11%
Merry-go-rounds	2%	9%	8%
Seesaws	3%	5%	5%
Total	100%	100%	100%

* Proportion of injuries for each type of equipment is presented separately for 0- to 4-year-olds and 5- to 14-year-olds, and is also shown for all 0- to 14-year-olds.

Source: Rutherford, G.W. (1979). *HIA hazard analysis: Injuries associated with public playground equipment*. Washington, DC: U.S. Consumer Product Safety Commission.

Note: Column percentages may not total 100% due to rounding.

Table 3 - 2B

Proportion of All Injuries Sustained on Each Type of Equipment by Each Age Group

	AGE OF VICTIM		
TYPE OF EQUIPMENT	0-4 Years	5-14 Years	Total
Climbers	10%	90%	100%
Swings	35%	65%	100%
Slides	21%	79%	100%
Merry-go-rounds	4%	96%	100%
Seesaws	11%	89%	100%

Source: Rutherford, G.W. (1979). *HIA hazard analysis: Injuries associated with public playground equipment*. Washington, DC: U.S. Consumer Product Safety Commission.

Table 3 - 3

Mode of Injury by Age of Victim*

MODE OF INJURY	AGE OF VICTIM 0-4 Years	5-14 Years	0-14 Years
Falls to surface	55%	59%	58%
Falls--struck same piece of equipment	8%	13%	13%
Falls--from one piece of equipment,struck another	1%	0%	1%
FALLS (SUBTOTAL)	64%	73%	72%
Fell against, onto stationary equipment	4%	10%	9%
Impact with moving equipment	28%	3%	7%
Protrusions, pinch points, sharp corners and edges	0%	5%	4%
Unknown	4%	8%	8%
Total	100%	100%	100%

* Proportion of injuries for each mode of injury is presented separately for 0- to 4-year-olds and 5- to 14-year-olds, and is also shown for all 0- to 14-year-olds.

Source: Rutherford, G.W. (1979). *HIA hazard analysis: Injuries associated with public playground equipment*. Washington, DC: U.S. Consumer Product Safety Commission.

Note: Column percentages may not total 100% due to rounding.

Table 3 - 4

Predominant Part of Body Affected and Injury Pattern
by Type of Equipment and Age of Victim
Data From King and Ball (1989)

	Age of Victim		
Type of Equipment	0-4 Years	5-14 Years	All Ages
Swings			
Part of Body Affected	head and face	upper limb	head and face
Predominant Injury Pattern	(1) superficial face (2) superficial head/ serious head	(1) upper limb fracture/ superficial face (2) superficial face/ upper limb fracture	superficial face
Slides			
Part of Body Affected	head and face	upper limb/head and face	head and face
Predominant Injury Pattern	(1) superficial face (2) serious head injury	(1) upper limb fracture (2) superficial face	superficial face; serious head injury more common than for other equipment types

(1) Denotes most frequent pattern of injury.
(2) Denotes second most frequent pattern of injury.

Table 3 - 4 (Continued)

Predominant Part of Body Affected and Injury Pattern
by Type of Equipment and Age of Victim
Data From King and Ball (1989)

	Age of Victim		
Type of Equipment	0-4 Years	5-14 Years	All Ages
Climbers			
Part of Body Affected	head and face	upper limb	upper limb
Predominant Injury Pattern	(1) superficial face (2) upper limb fracture/ serious head injury	(1) upper limb fracture (2) superficial face	upper limb fracture; upper limb fracture more common than for other equipment types
Seesaws			
Part of Body Affected	head and face	head and face	head and face
Predominant Injury Pattern	(1) superficial face (2) superficial head/ lower limb fracture	(1) superficial face (2) superficial head/ upper limb fracture	superficial face; lower limb fractures and trunk fractures more common than for other equipment types

(1) Denotes most frequent pattern of injury.
(2) Denotes second most frequent pattern of injury.

4. DEVELOPMENTAL CONSIDERATIONS

4. DEVELOPMENTAL CONSIDERATIONS

4.1 PHYSICAL DEVELOPMENT (FINE MOTOR AND GROSS MOTOR DEVELOPMENT)

4.2 COGNITIVE DEVELOPMENT
4.2.1 Characteristics of the sensorimotor child (birth to 2 years)
4.2.2 Characteristics of the preoperational child (2 through 6 years)
4.2.3 Characteristics of the concrete operational child (7 to 12 years)

4.3 SOCIAL DEVELOPMENT
4.3.1 Characteristics of the toddler (1 to 2 1/2 years)
4.3.2 Characteristics of the preschooler (2 to 5 years)

4.4 CONCLUSION

4. DEVELOPMENTAL CONSIDERATIONS

This section of the report provides an overview of the major developmental considerations that influence the design and use of playground equipment. The discussion provides background on significant developmental trends and milestones in the areas of motor skills, cognitive abilities, and social interaction for young children. Further, it highlights some of the important functions of playground equipment which need to be considered when evaluating safety criteria. The role of adult supervision of young children in the playground environment is also discussed. The developmental considerations summarized here played a critical role in developing the design/use recommendations for this report (see Section 5).

For young children, their play is their work. It is much more than the diversionary leisure activity that it is for adults; through play, children develop their intellectual, social, emotional, and physical (fine motor and gross motor) skills, as well as their linguistic skills (Rubin, Fein, and Vandenberg, 1983; Frost, 1988). Play is thus an adaptive activity that reflects both children's current abilities and serves as a bridge to the development of additional abilities (Rubin et al., 1983). Playground equipment can, therefore, serve not only as outlets for physical development, but also for development in the other domains. For preschoolers (children 2 to 5 years old), playground equipment should stimulate physical activity, invite cooperative play, foster other social-emotional development, and support the growth of more complex linguistic structures. Moreover, equipment which supplies a variety of spatial relationships (e.g., having to go through tunnels, up or down ramps, over or under platforms), flexible-use equipment, and creative "small parts" materials (e.g., clay, carpentry, paints, water, sand, etc.) are playground elements which can be made safe, and can also spur cognitive development (Frost, 1988; Moore et al., 1987).

Young children can thus "exercise" all aspects of their development on playgrounds. It is difficult to discuss one aspect of development (e.g., physical, cognitive, or social-emotional) separate and apart from the others, because all aspects of development are interrelated and contribute to the total growth of the child: the developmental sequence in one area is constantly influencing and enhancing development in another. However, in order to show the characteristics of each domain, the domains will be discussed separately.

A chart of developmental milestones in each domain and their implications for playground use is also presented (see Table 4 - 1). It is important to recognize that the milestones in different areas of development do not always occur simultaneously. As discussed below, divisions in the stages of cognitive and social development are marked by different age groups, according to when significant milestones occur in each realm. Thus, what is a significant *social* milestone or change in behavior may occur at a different point in a child's development than a significant *cognitive*, or *physical* change. It must also be remembered that these divisions have "fuzzy" boundaries, and that there will always be individual differences in development in any of the domains, not necessarily consistent across domains. For example, a child's gross and fine motor development may occur much earlier than his ability to cognitively relate cause and effect, leading to an increase in potential risk on the playground.

4.1 PHYSICAL DEVELOPMENT (FINE MOTOR AND GROSS MOTOR DEVELOPMENT)

Though young children do have a rudimentary sense of the physical limitations of their own bodies, the playground and its equipment offer them numerous opportunities to test, practice, refine, and extend the limits of their physical abilities, while having fun. On the playground, children's social contacts with their peers evolve, to a large extent, through common motor activities. Thus, children's motor development has a significant influence on social and cognitive behavior; for example, a child who is not as advanced in his or her gross motor skills is more likely to be frustrated or afraid than one who is more adept. It must be remembered that children differ in their *rates* of physical growth, their *uniformity* of physical growth, and in their *potential* for physical growth.

During the toddler years, which end at approximately 2 to 2 1/2 years, children experiment with different kinds of movement and with the locations of their bodies in space. Although they will want to use playground equipment once they learn to walk (9 to 18 months), most toddlers are not ready, in the gross motor or other realms of development, for independent access to standard slides, swings, or climbers. They enjoy large sandboxes, open cubes to play within, and simple slides (Steele and Nauman, 1978). By 25 to 27 months, toddlers practice stepping, running, and climbing on stairs or other small objects (Aronson, 1988; Makolin and Denham, 1976). By 28 to 30 months, they can rock independently on spring animals for three minutes without falling or sliding off (Makolin and Denham, 1976).

Preschoolers build their motor skills, especially strength, balance, and coordination, through experimentation with ever more challenging situations (Aronson, 1988). When they begin jumping from low heights of about one foot and have the ability to use the "lock grip" (i.e., fingers and thumb wrapped around the handhold part of the equipment) around 2 1/2 to 3 1/2 years, and demonstrate proficiency in stair climbing (i.e., alternating feet, rarely needing a railing) around 3 to 3 1/2 years, young children can be allowed access to more challenging playground equipment (Aronson, 1988; Makolin and Denham, 1976). Balance develops considerably from 3 to 6 years: children can not be expected to climb up to the top of a 5-foot slide until 3 1/2 to 4 years old or to climb rung ladders until 4 1/2 to 5 years (Makolin and Denham, 1976). However, coordination is not fully developed in even most older preschoolers, so falls must be expected. Upper body strength develops continuously. Toddlers are probably not ready for most upper body devices, such as overhead ladders; and although 4- and 5-year-olds will begin experimenting with upper body devices, most children probably won't master the combination of upper body strength and coordination needed for such equipment until their school-age years.

With regard to fine motor control, strength and agility also increase during the preschool years. The most important change is the ability to use the "lock grip," as mentioned above (Aronson, 1988). Other fine motor milestones (e.g., drawing a circle, building a tower of eight 1-inch cubes, drawing a man with three to six parts, and copying a square), though vital in the preschooler's development, appear to have little direct bearing on playground use, except for drawing in the sandbox or using sandbox toys and other small parts.

The rapid physical growth that occurs during the preschool years needs to be supported through opportunities for motion on the playground. Equipment should give children the chance to practice using their arms to reach, grasp, push, pull, and hang, and their legs and feet to walk, run, jump, climb, and other forms of locomotion. It is extremely important, however, that the equipment on which children practice these skills be appropriate for their physical size and shape. Children may be at greater risk of injury if there is a mismatch between their physical size and skills and the size of the equipment. Throughout this report, consideration is given to the different sizes and shapes of children in the two age groups when recommendations are made regarding various dimensions of equipment. Anthropometric data provides the basis for many of these recommendations (see Section 2); the difference between the age groups for certain body dimensions can be quite large. Body dimensions such as stature, standing center of gravity, vertical grip reach, seated height, shoulder breadth, chest breadth, torso depth, buttock-foot length, arm length, hand dimensions, and head dimensions play a critical role in design of playground equipment, and since these dimensions are constantly changing as children grow, attention must be given to designing appropriately-sized equipment for children at various stages of physical growth.

4.2 COGNITIVE DEVELOPMENT

Piaget's separation of cognitive development into three stages 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 (Ginsburg and Opper, 1988).

4.2.1 Characteristics of the sensorimotor child (birth to 2 years)

During the sensorimotor years, the child learns about the world as a result of incoming sensory inputs, and of the muscular responses to these inputs. Based on these experiences, the child begins to create an organized system of knowledge about his world (Ginsburg and Opper, 1988).

Children are beginning to develop a rudimentary sense of cause and effect in specific situations during the sensorimotor period. However, they do not have a global enough understanding of cause and effect to apply this knowledge in any systematic way to the many situations that may be encountered on the playground.

They are also very egocentric, often unable to imagine more than one point of view--their own--in any given situation. They are unable to put themselves in someone else's place and take another point of view into consideration; in fact, it is probably not chance that parents begin to teach children what it feels like to be the other person by saying, "How would you like that if he did that to you?". Further, children at this stage can typically only concentrate on one central fact or idea at a time, which is referred to as centration.

During the sensorimotor stage of cognitive development, children have only a limited understanding of their physical abilities and limitations. This may cause them to attempt feats that they are not developmentally ready to handle. Combined with their lack of a global understanding of cause and effect, egocentrism, and tendency to centrate, this dictates a need for complete adult supervision on playgrounds. It is essential that the equipment very young children play on be designed with their specific development capabilities in mind.

Children at this point may have had some previous playground preparatory play experience with infant wind-up swings or very small two- or three-step slides; and, certainly, they all experiment with climbing in the home environment. Thus, they will be interested in similar equipment and experiences on the playground. Parents can build on these past experiences as they introduce the child to the swings and other apparatus of the playground. Because of reinforcement's powerful role in a young child's learning, safe use of playground equipment and the achievement of any feat related to the play on equipment (e.g., the child climbing to the top of a small slide and sliding down) should be both praised and carefully supervised.

Thus, for the sensorimotor child, there should be an emphasis on practicing and mastering the physical feats of using the equipment with risk-taking held to a minimum. It needs to be re-emphasized that the play activity should be done with the interaction of the adult. Using swings as an example, the child does not have the understanding of what creates momentum, nor the muscular control and coordination to propel his or her body in space. Adults should push the swings while kneeling in front of the child (Aronson, 1988), so the child can see what is happening, know when the push is coming, and brace the body appropriately. He or she is also not as likely to be pushed out of the swing as when pushed from the back.

4.2.2 Characteristics of the preoperational child (2 through 6 years)

Though more cognitively advanced than the sensorimotor child, the preoperational child is still forming self-concepts. Preoperational children are often still quite egocentric, and initially unable to take any viewpoint other than their own, which may be a factor in certain injury scenarios (Ginsburg and Opper, 1988; Schaffer, 1988). They may only consider their own desires to use a piece of equipment, and refuse to consider the presence of another child as a valid reason to moderate their behavior, even in the light of potential injury (e.g., jockeying for position on a slide or climbing apparatus). This rigidity moderates as children move through the preoperational period.

Centration also remains characteristic of children through the preoperational years. Because they still have trouble focusing on more than one aspect of a situation, young children cannot take in multiple bits of information and process them simultaneously (Schaffer, 1988). Like egocentrism, the continued tendency to centrate may present some risk of injury on a busy playground.

Children this age may not be attentive to peripheral stimuli, and this inability to process cues in the peripheral visual field may help account for certain injury patterns, such as being struck by a swing from the side, since preoperational children may not attend to swings at the "other" end of their arc (Paris and Lindauer, 1982).

Other attentional abilities are also still developing; for example, they are still easily distracted in situations calling for selective attention (Higgins and Turnure, 1984), such as being distracted by a friend on the ground while trying to get adjusted and ready to slide down from the top of a sliding chute. Very young preoperational children tend to wander from activity to activity (Pillow, 1988), such as from seesaw to slide to climber, with little perception of risk in each setting or in traveling from one to another. The layout of playground equipment and pathways must take into account the child's limited range of attention. Scanning of the visual environment for hard-to-see but important details, such as a badly misshapen S-hook on a swing, a loose rung on a slide, or protruding sharp edges on a merry-go-round, is difficult for the preoperational child (Vurpillot, 1968).

Children's understanding of cause and effect relationships is much more complex than it was in the sensorimotor period, but preoperational children searching for causes of events often tend to reason from one specific fact to another and miss the true causal relationship. This deficit is called transductive reasoning (an example would be Piaget's daughter's assertion during this period that "I haven't had my nap so it can't be afternoon") (Schaffer, 1988). Two characteristics of the illogical thinking during this stage are artificialism and animism. In artificialism, children confuse physical and supernatural causes; for example, it seems imminently logical to a 3-year-old that Superman has the power to fly. Assuming that this is how the causal world works, the preoperational child has a strong urge to emulate these powerful figures--often with disastrous results. In animism, children believe that non-animate objects are in fact alive and can cause events (e.g., "that climber hurt me"; "the swing is mad at me and hit me"). Such reasoning obviously does not advance safety on the playground.

Although the preoperational child does have some experience in hypothesis testing and some understanding of rudimentary cause and effect relationships (e.g., that causes always precede effects, the order of a causal event sequence, the ability to pick out causes of events), this understanding is still imperfect (Gelman, 1978; Gelman, Bullock, and Meck, 1980; Ginsburg and Opper, 1988; Schaffer, 1988; Sedlak and Kurtz, 1981). Thus, in the sequence "climb up ladder--slip--fall," early preoperational children can identify falling as the effect rather than the cause; but in a new situation with which they have had little or no experience (e.g., climbing onto a new slide for the first time), these children are not able to reason or predict causally. Moreover, they have not reached the level of development which would permit them to anticipate events. Again, using swing-related moving impact incidents as an example, preoperational children cannot estimate how fast they must move in order to clear the path of a rapidly approaching swing. Typically, the child is "centering" on an important, singular task, such his or her destination, and, therefore, does not consider other important environmental information (e.g., the other approaching swing).

Another deficit of preoperational children's thinking which may be a factor in some playground injuries is that they have not yet attained reversible thinking (Schaffer, 1988). Children are unable to go through a set of steps and then reverse the process mentally in order to assess the possible consequences of the action before they actually physically perform the feat. This deficit can lead children into "no way out" situations such as climbing up to a slide platform, finding that the height is too great, and then not being able to slide down. Even when preoperational children can physically retrace their steps (i.e., coming back down the slide ladder or stairway), they are generally putting themselves at greater risk for falls. This cognitive characteristic should be taken into consideration when designing playground equipment for young children so that "no way out" situations do not have to be encountered.

During the late preoperational period, the symbolic function is achieved (Ginsburg and Opper, 1988). The child can now mentally maintain an image from the environment and utilize symbols or representations of other realities. This allows the preoperational child to move into the world of pretend play, to take non-reality based roles in dramatic play, and to become the omnipotent creator of his own world.

Dramatic play is one cognitive category of play, involving the substitution of imaginary objects for real objects, animals, or people. Children engage in dramatic play beginning between 24 and 30 months and some continue to do so throughout the preoperational years; typically, the amount of dramatic play peaks around 5 years (Rubin et al., 1983). Boys in particular engage in dramatic play on playgrounds and can become quite boisterous in playing out their roles. Cooperative social play often occurs simultaneously as children use playground equipment to implement these fantasies. They may pretend that playhouses or parts of climbers are such places as home, school, castles, airports, or hospitals. Dramatic play increases when portable, small parts such as plastic cups, trucks, cars, toy animals and/or people are included in the playground environment.

Another type of cognitive play is constructive play, during which children develop intellectually by creating objects and constructions (Rubin et al., 1983). Preoperational children enjoy digging tunnels and building castles and cities in the sand, and also may use playground areas to build with blocks and tires.

The achievement of the symbolic function, along with rapidly developing linguistic skills allow for more peer interaction on the playground, as the preoperational child participates in dramatic play and constructive play projects. Good design of preschool playgrounds should reflect these developmental characteristics and provide stage-like areas to promote these types of play.

4.2.3 Characteristics of the concrete operational child (7 to 12 years)

After the preoperational period, at approximately 7 years of age, the child enters the stage of concrete operational thinking (Ginsburg and Opper, 1988). Children are now capable of reversible thinking, which enables them to be much more logical in cause and effect reasoning. They are now able to reason from cause to effect, and then think back to the cause and how to change it to get a new effect. This new development in logical thinking helps decrease risk on the playground; for example, if a child plans to go up a very tall slide, he or she can mentally predict the possible outcome, and reason backward to modify the plan, perhaps not climbing up into a "no way out" situation.

In addition, the concrete operational thinker is no longer centered on one aspect of a problem, so that potentially dangerous and potentially entertaining aspects of playground equipment can be attended to simultaneously. Egocentrism also fades, so that other children's physical or social points of view can be taken into account. Perceptually, children also are less apt to be distracted. Grade school children have many new cognitive abilities that interact to render them safer on the playground. It is also important to recognize their changing motor and cognitive abilities now allow them to participate in group activities and games with rules, like hopscotch and kickball, on the playground.

4.3 SOCIAL DEVELOPMENT

4.3.1 Characteristics of the toddler (1 to 2 1/2 years)

Limiting toddlers' behavior can be difficult, because they focus on the "here and now," and try to become autonomous and do things "my way" (Erikson, 1953). Adults must, therefore, limit toddlers' behavior by steering them to appropriate play equipment alternatives, such as described above and in the design recommendations (see Section 5).

Adults should not expect toddlers to be able to control their own behavior in the face of hazards. Instead, the child should be expected to respond to an adult's "No"; this is developmentally appropriate. It could also be effective for the adult to give a running commentary on what is acceptable behavior while toddlers play on the equipment, rather than giving a long list of rules beforehand (and expect the toddler to follow it). Although toddlers need almost total adult supervision through age 2, the relative infrequency of peer interaction at this age may make some aspects of this supervision simpler than the supervision of older preschoolers.

4.3.2 Characteristics of the preschooler (2 to 5 years)

Toward the end of the toddler stage, 2 to 2 1/2 years, the child becomes less egocentric and uncompromising. For example, 2 1/2-year-olds may begin to ask for a turn, even though they may not be able to wait appropriately for that turn until a year later (Makolin and Denham, 1976). In fact, the advent of self-control is a highlight of social development in the age range from 2 to 5 years. Children begin to use self-control around 2 years, especially if the adult is present to remind them of rules and prohibitions. It is not until after 4 years, however, that children can self-monitor: remind themselves of the rules, and use self-imposed strategies to follow them, when no adult is present (Kopp, 1982). Thus, during the preschool period, adults can lessen their "hovering" somewhat, but will still need to intervene fairly frequently. After age 4, children may begin to actually remind themselves of dangerous versus non-dangerous practices, so adult supervision may be less stringent. The observational study supports these trends. However, as discussed below, other developmental trends in showing off and experimentation may dictate a need for greater supervision.

Preschoolers focus much of their play not only on self-control, but also on socialization skills, and on the definition of various roles in their social world (Aronson, 1988). They often imitate the activities of older children and adults, whether on the playground, in family life, or on television; in fact, such imitation drives much of their learning at this age (Aronson, 1988; Bandura, 1977). Regarding playground equipment use, however, preschoolers sometimes lack the necessary physical skills and self-control safeguards to safely complete such imitation (Bandura, 1977).

Preschool children participate in several types of social play: solitary, parallel, associative, and cooperative (Rubin et al., 1983). In *solitary* play, the child is, as the name suggests, essentially alone. Observational data have shown children engaged in this type of play sitting alone, in a tire tunnel, for example, or under steps on a climber. During *parallel* play the child plays near, or next to another child, but they are engaging in separate activities. An example of parallel play is one child swinging on his or her stomach, for an extended period of time, while another repeatedly climbs the ladder of an attached superstructure and sits on the platform. *Associative* play is defined by the child's play near another, engaging in and even discussing the same activity, but still not negotiating roles. Two children might sit side-by-side in the sandbox, chatting, as they are involved in separate "road-building" and "cooking" activities. In *cooperative* play, children are not only interacting, as in associative play, but also negotiating roles (e.g., "you be the doctor...") and working together to a common end. On a playground climber, children might be heard saying, "I'm the captain on this ship. You guys be my men and we'll be pirates!" "Okay, let's sail!"

Solitary and parallel play are the predominant types from 24 to 30 months, and then decrease in frequency to moderate levels between 4 to 5 years. Much solitary and parallel play between 4 and 5 consists of creating constructions, reading, etc., and may no longer be common on the playground, although there should still be a place to be alone--perhaps to allow anger, shame, or other strong emotion to dissipate--and a place to play alongside others (Esbensen, 1987). Thus, younger preschoolers are likely to be found alone or near one or two others, and as such, may be easier to supervise. Associative and cooperative play increase, especially by 3 1/2 to 4 years (Rubin et al., 1983). Pushing others on the swing, pulling another child on the tire net, waiting a turn on the slide, playing games on the grass are all activities that help older preschoolers develop social skills. However, adults should be aware that children in groups may become more boisterous and it may be more difficult to monitor all their potentially dangerous actions on playground equipment.

Social interaction patterns also change during the preschool period (Hartup, 1983). Social participation itself increases, as the above analysis of play would suggest. Although the frequency of aggression and rough and tumble play increases, the proportion of negative social behavior decreases because of the larger increases in positive peer interaction. Competition also increases, and quarrels, although fewer in number, tend to last longer. Positive social behavior develops through positive peer interaction, cooperation, attention, approval, and acceptance. Thus, more will be "happening" on the playground where older preschoolers are involved and play will be more complex. There will be sophisticated cooperative play, fighting, discussions, laughter, and much noise. Children are no longer merely concentrating on motor skills; they are exercising motor skills in the context of rich, ongoing, ever-changing social relationships.

Play on the playground also affects growing children's sense of self-esteem, or self-perceived competence (Harter, 1983). The preschoolers' sense of self is tied to their cognitive abilities: it is very hard, if not impossible, for them to think in general psychological terms about themselves. They are, however, making evaluations about their own social, cognitive, and physical competencies. Feeling capable to use playground equipment adequately and correctly promotes children's self-esteem. In contrast, unsafe, overcomplicated, or boring equipment will not give children the opportunities they need to be successful and increase these feelings of competence.

At the same time, 4-year-olds begin calling attention to their own performance (i.e., "showing off"), and children are not careful with others' property until 5 1/2 to 6 (Makolin and Denham, 1976). Such social attributes suggest that some risk-taking, without concomitant thought about self and others' safety, is a normal phenomenon at this age but may lead preschoolers to dangerous behaviors on the playground. This is further compounded by the cognitive limitations of preschoolers discussed previously. Children begin to try to avoid accident-provoking circumstances by 2 1/2 to 3 years old, but this ability is far from developed; it is not until 4 1/2 to 5 years that one may expect the child to begin to go about the neighborhood unassisted, exhibiting the beginnings of independence and safe behavior in the environment (unless showing off is still a problem).

Social development in the preschool period is very complex. The above trends in social development (self-control, imitation, pretense and cooperative play, risk-taking, and mastery motivation) do, however, converge to paint a picture of children who are experimenting with elements of their wider world. This drive for experimentation and imitation strongly suggests that playgrounds should provide opportunities for preschoolers to practice new motor and social skills as safely as possible, often under the *direct* supervision of adults. However, as implied above with regard to the development of self-control, the role of the adult changes somewhat during the 2 to 5 years age range. In the early period, children will need much motor and self-control assistance, and will look to the adult for this assistance on playground equipment. Later, they will spend more and more time in direct interaction with peers, will self-regulate more, and will seek the adult as a resource only (Hartup, 1983). The wise adult caregiver, however, realizes that his or her role is not obsolete. Although children are more peer-oriented, more capable of self-regulation, and need to master the environment themselves to build self-esteem, at least passive adult supervision is still needed, because of the older preschooler's potential lack of attention to danger and showing off.

4.4 CONCLUSION

Young children are curious, active, and engage in self-exploration in order to arrive at their own views of the world (Lay-Dopyera and Dopyera, 1987). The playground provides stimulus complexity and novelty, through which children can exercise their need to explore (Berlyne, 1960). Play theory asserts that such exploration in turn leads to mastery of an activity, and thence to experimentation, or re-creation of a new type of novelty (Brown, 1978). This suggests that preschoolers will, in a novel playground environment, explore all the "normal" ways of using the equipment which are within their capabilities, and that the more daring ones may then experiment with newer, potentially hazardous, play behaviors on the equipment. During such experimentation, preschoolers may put themselves at risk of injury when they overestimate their physical abilities and underestimate their developmental maturity. For example, a child was seen climbing on the *outside* of a tube slide, during the observational study.

Information concerning the preschooler's motor, social, cognitive and perceptual abilities must be understood by the designers of early childhood equipment and play spaces, so that these abilities can be taken into consideration in the design and layout of the preschool playground. Development during the preschool period is not simply linear: for example, while children are becoming socially more able to control themselves vis a vis adult requirements, they also are becoming showoffs and more hostile in their peer aggression; and, while they are acquiring better balance, they are also trying more playground pieces and moving faster. Often one element of development which indicates a need for greater playground safety seems to contradict another element of development which points to greater playground risk. Only full exploration of the nature of the young children's developmental abilities at each age will lead to the design of playground equipment which simultaneously promotes safety and challenge.

A table of significant developmental milestones follows. Examples are given to illustrate the implications of these developmental changes for playground design and use. However, the implications listed should be viewed as examples, not as an exhaustive list.

Table 5.1 - 1

ORGANIC LOOSE MATERIAL

Summary characteristics of generic features, wood chips, and bark nuggets

GENERIC FEATURES

Fall Absorbing Characteristics	Cushioning effect depends on air trapped within and between individual particles, and presupposes an adequate depth of material.
Size/Shape/Other Characteristics	Depends on specific material.
Installation/ Maintenance	Should not be installed over existing hard surfaces (e.g., asphalt, rock). Method of containment needed (e.g., retaining barrier, excavated pit). Good drainage required underneath material. Requires periodic renewal or replacement and continuous maintenance (e.g., leveling, grading, sifting, raking) to maintain appropriate depth and remove foreign matter.
Advantages	Low initial cost. Ease of installation. Good drainage. Less abrasive than sand. Does not attract cats and dogs (compared to sand). Attractive appearance.
Disadvantages	The following conditions reduce cushioning potential: 1. Environmental conditions: rainy weather, high humidity, freezing temperatures. 2. With normal use, combines with dirt and other foreign materials. 3. Over time, decomposes, is pulverized, and compacts. 4. Reduced depth of materials: blown by wind, displaced by children's activities.

Table 5.1 - 1 (continued)

ORGANIC LOOSE MATERIAL
Summary characteristics of generic features, wood chips, and bark nuggets

GENERIC FEATURES (continued)

Disadvantages (continued)	Can be blown or thrown into children's eyes. Ideal for microbial growth when wet. Conceals animal excrement and trash (e.g., broken glass, nails, pencils, and other sharp objects that can cause cut and puncture wounds). Spreads easily outside of containment area. Increased problems with deterioration of wood equipment posts (compared to inorganic material). Can be flammable. Can be stolen for use as mulch by residents.

Table 5.1 - 1 (continued)

ORGANIC LOOSE MATERIAL
Summary characteristics of generic features, wood chips, and bark nuggets

WOOD CHIPS

Fall Absorbing Characteristics	See generic features of organic loose material.
Size/Shape/Other Characteristics	Smallest chips work best. Coniferous chips more durable than deciduous. Coniferous chips and softer hardwoods (e.g., sycamore) not as splintery as hardwood chips, when first spread.
Installation/ Maintenance	See generic features of organic loose material. Expected lifetime 4 to 7 years.
Advantages	See generic features of organic loose material. Preferable to bark nuggets except where initial abrasiveness of chips is a problem; lower cost and easier to maintain than nuggets. Readily available. Easier to police for broken glass than bark nuggets or sand.
Disadvantages	See generic features of organic loose material. Can splinter, especially when first spread; initial abrasiveness disappears with wear and weathering. Sticky sap and resin may be present. Wood chips from chemically treated timber should not be used.

Table 5.1 - 1 (continued)

ORGANIC LOOSE MATERIAL
Summary characteristics of generic features, wood chips, and bark nuggets

BARK NUGGETS

Fall Absorbing	See generic features of organic loose material.
Size/Shape/Other	Typically from 0.5 to 1 inch screen size.
Installation/ Maintenance	See generic features of organic loose material.
Advantages	See generic features of organic loose material.
Disadvantages	See generic features of organic loose material. Retain water. Their softness accelerates decomposition; after relatively short period, reduced to soil-like compost with severely reduced cushioning potential. Top surface may conceal compaction underneath. When dry, bark dust blows in eyes; some children allergic to bark dust. Initial cost high relative to wood chips.

Table 5.1 - 2

INORGANIC LOOSE MATERIAL

Summary characteristics of generic features, sand, gravel, shredded or chopped tire

GENERIC FEATURES

Fall Absorbing Characteristics	Conforms to shape of falling child, spreading the area of impact and increasing its duration, thus reducing the potential for injury.
Size/Shape/Other Characteristics	Canadian draft standards (CAN/CSA-Z614, 1988) do not permit the use of crushed stone under equipment, due to its abrasiveness.
Installation/ Maintenance	Should not be installed over existing hard surfaces (e.g., asphalt, rock). Method of containment needed (e.g., retaining barrier, excavated pit). Good drainage required underneath material. Requires periodic renewal or replacement and continuous maintenance (e.g., leveling, grading, sifting, raking) to maintain appropriate depth and remove foreign matter.
Advantages	Low initial cost. Ease of installation. Does not pulverize. Not ideal for microbial growth. Generally nonflammable, except for rubber products.
Disadvantages	The following conditions reduce cushioning potential: 1. Environmental conditions: rainy weather, high humidity, freezing temperatures. 2. With normal use, combines with dirt and other foreign materials. 3. Reduced depth of materials: blown by wind, displaced by children's activities. Can be blown or thrown into children's eyes. Can be swallowed. Conceals animal excrement and trash (e.g., broken glass, nails, pencils, and other sharp objects that can cause cut and puncture wounds). Spreads easily outside of containment area.

Table 5.1 - 2 (continued)

INORGANIC LOOSE MATERIAL
Summary characteristics of generic features, sand, gravel, shredded or chopped tire

SAND

Fall Absorbing Characteristics	See generic features of inorganic loose material. No compressibility.
Size/Shape/Other Characteristics	Requisite type of sand is produced by interaction with water (e.g., washed river bed sand, grain, or bird's eye sand). Sand should be clean, washed; washed sand is less likely to become compacted. Particles should be round in shape and as uniform in size as possible. Particles should be hard; sand derived from hard rock lasts longer than sand composed of soft stone particles. Should not contain silty or clay particles, or any artificially crushed material.
Installation/ Maintenance	See generic features of inorganic loose material. Compacted sand should be turned over, loosened, and cleaned.
Advantages	See generic features of inorganic loose material. Low cost (most of the cost is transportation-related). Preferable to gravel. Not susceptible to vandalism other than by contamination.
Disadvantages	See generic features of inorganic loose material. Narrow range of allowable particle sizes, due to binding and eye injury problems. Small particles bind together and become less cushioning when wet; when thoroughly wet, sand reacts as a rigid material. May be tracked out of play area on shoes; abrasive to floor surfaces when tracked indoors; abrasive to polyethylene materials. Adheres to clothing. Susceptible to fouling by animals. May accelerate corrosion of wood equipment supports because it retains moisture, but less so than organic loose material.

Table 5.1 - 2 (continued)

INORGANIC LOOSE MATERIAL
Summary characteristics of generic features, sand, gravel, shredded or chopped tire

GRAVEL

Fall Absorbing Characteristics	See generic features of inorganic loose material. No compressibility.
Size/Shape/Other Characteristics	In Mahajan and Beine's study (1979), gravel displayed peak g values of 200 at a drop height of 2 feet. New data on impact performance of different sizes of gravel are being collected by the CPSC, and should clarify whether gravel can be a suitable surface for higher potential fall heights. Gravel should be clean, free of soil; unscreened river gravel is unacceptable. Particles should be round in shape.
Installation/ Maintenance	See generic features of inorganic loose material. Requires periodic break up and removal of hard pan.
Advantages	See generic features of inorganic loose material. Not susceptible to vandalism other than by contamination. Less attractive to animals than sand.
Disadvantages	See generic features of inorganic loose material. Difficult to walk on. Hard pan may form under traveled areas.

Table 5.1 - 2 (continued)

INORGANIC LOOSE MATERIAL

Summary characteristics of generic features, sand, gravel, shredded or chopped tire

SHREDDED OR CHOPPED TIRE

Fall Absorbing Characteristics	In addition to conforming to shape of falling child, shredded tire traps air between particles to provide a cushioning effect.
Size/Shape/Other Characteristics	Commercially available in particle sizes ranging from 0.08 by 0.20 inch to 2 inches.
Installation/ Maintenance	See generic features of inorganic loose material.
Advantages	See generic features of inorganic loose material. Slow decomposition.
Disadvantages	See generic features of inorganic loose material. Can be flammable. Subject to vandalism (e.g., ignited). Retains heat in direct sun. Toxicity under normal use has not been evaluated. Plastic bond surface that is sometimes used to prevent dispersion of material deteriorates with wear.

Table 5.1 - 3

UNITARY SYNTHETIC MATERIALS

Summary characteristics of generic features of rubber mats, synthetic turf on foam mats, rubber sheeting on foam mats, poured in place urethanes, and rubber compositions

GENERIC FEATURES

Fall Absorbing Characteristics	Consists of shock absorbing materials such as rubber.
Size/Shape/Other Characteristics	Thickness ranges from 1 to 6 inches. These materials vary considerably in composition and design and in their suitability for different play settings and climatic conditions. Therefore, properties presented here may not apply to all types of unitary synthetic products.
Installation/ Maintenance	Require expert under-surface preparation and installation. Installation of resin-bound rubber particles cast on site may involve use of hazardous material. Minimal maintenance.
Advantages	Low maintenance. Easy to clean. Consistent shock absorbency. Material not displaced by children during play activities. Generally low life cycle costs. Good footing (depends on surface texture). Harbors few foreign objects. Generally no retaining edges needed.
Disadvantages	Initial cost relatively high. Will not conform to shape of falling child. Undersurfacing can be critical for thinner materials. Often must be used on almost level uniform surfaces. Can be flammable. Subject to vandalism (e.g., ignited, defaced, cut). For drop heights that exceed about 5 feet, some synthetic mats "bottom out," or reach their maximum compression before impacting body comes to complete stop, increasing injury risk. Full rubber tiles may curl up and cause tripping. Some designs susceptible to frost damage.

TABLE 4 - 1A
DEVELOPMENTAL MILESTONES:
GROSS MOTOR DEVELOPMENT (see also Hottinger, 1980)

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
18-24 Months	• Walks sideways. • Walks backwards. • Walks up steps one foot at a time; needs rail. • Hurried walk. • First true run; "waddles" and often falls.	• Increasing postural control of trunk allows for primitive use of playground equipment. Still large risk of falling. • Based on improved balance, can now rock on spring-based equipment alone.
	• Steps down from low objects.	• Can get down off low equipment.
	• Kicks large ball forward by kicking "at" it. More often moves at ball. • Throws ball overhand without body rotation, forearm extension only.	• May lose balance when investigating these new activities; playground surfaces should absorb falls even when toddlers are not on equipment.
24-30 Months	• Jumps up and down in place. • Movement is hurried. • Turns corners while running or walking. • Runs with a bit more balance. • Walks up and down stairs with support. • Jumps from 8" to 10" step.	• Limb and trunk movements becoming more agile; may begin to try to be more independent, as in getting on and off equipment.
	• Does not avoid obstacles.	
	• Climbs ladder, using arms and legs alternatively.	• More finely coordinated; better timing in use of equipment.
3 Years	• Walking and running are routine; however, still flat-footed, with stops and starts. • Cannot turn quickly while running.	• More active on playground, but still falling sometimes.

TABLE 4 - 1A (continued)

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
3 Years (continued)	• Pedals tricycle.	
	• Balances on one foot for 1 second. • Walks on wide balance beam. • Hops 3 times on preferred foot. • Walks up stairs alternating feet by end of year; still *marking time* foot pattern in descending stairs. • More coordinated leg and foot movement.	• Static balance, such as balancing on one foot is more skillful, and dynamic balance, such as hopping, or walking up stairs, is increasingly necessary on the playground.
	• Climbing on and off low items; higher heights conquered.	• Trying more independent use of playground equipment.
	• Tries stunts beyond ability. • "Basket" catch using whole body; may fear object to be caught. • Rotates body when throwing.	• Gets self into trouble. • May lose balance, fall, in various activities.
4 Years	• Able to whirl, swing, somersault. • Runs more agilely with stopping and going, better around corners. • Balance on one foot; 5 sec. • Hops on one foot 4 to 6 times. • Heel-to-toe walk. • Pumps swing with balance.	• Static and dynamic balance are improving. • Independent use of much playground equipment possible.
	• Speed and stride length are increasing; learning to gallop, a combination of walking and a leap with the same foot leading. • One-footed skip.	• Moving faster through space; greater agility paired with greater participation on the playground and speed of movement through space.

TABLE 4 - 1A (continued)

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
5 Years	• Less supervision needed--grace, ease, economy of motion. • Catches a small bounced ball with hands only. • Ascends and descends long stairs or ladder with alternating feet. • Balances on one foot: 10 sec. • Can use a narrow balance board, getting foot off only twice. • Jumps for height (1 ft.). • Running broad jump up to 3 ft. • Hops 8-10 times on same foot. • Galloping more versatile. • Skipping skillful for 20% of this age population. • Kicks soccer ball into air.	• Gross motor skills well articulated. • Has attained enough gross motor skill that most dangerous situations will probably occur because of cognitive limitations and peer interaction. • Static balance excellent.
6 Years	• Backward heel-to-toe walk. • Skipping skillful for most.	• Dynamic balance excellent.
	• Skill in catching, striking, throwing, and ball bouncing.	• Beginning skills necessary for games with rules are in place, these will obviate attraction for playground equipment.

TABLE 4 - 1B
DEVELOPMENTAL MILESTONES: SOCIAL DEVELOPMENT

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
18-24 Months	• Pretend play begins.	• Will profit from small parts on playground, because these promote pretend play.
	• Solitary and parallel play predominant. • Control of behavior; obeys adults.	• Needs much supervision to promote peer interaction and safety.
24-30 Months	• Beginning "self" control; sometimes behaves with control when adult is not around.	• Still needs supervision, although may remember a few rules--sometimes too late.
	• Aggression is oriented around a goal (e.g., an object struggle).	• Needs supervision for this new and different problem which may easily impact safety.
	• Much imitation continues.	• May now imitate more, attempt less-safe activities.
	• Asks for a turn.	• Expects to get a turn when asks, may become more frustrated when peers do not cooperate.
3 Years	• Associative and cooperative play is beginning to increase.	• Better able to coordinate activities with others, leading to an increase in safety.
	• Starting to evaluate self: self-esteem.	• Will feel bad about self if unable to accomplish playground skills.
	• Begins to see accidents and tries to avoid them, but not always successful.	
	• Easily distracted.	

TABLE 4 - 1B (continued)

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
4 Years	• Begins to use internal strategies for self control.	• Adult training may have more impact, even though supervision still important.
	• Waits for a turn.	• Less danger of unsafe behavior around turn-taking.
	• More social interaction with peers.	• Playground more chaotic, supervision more difficult.
	• More aggression in absolute number of behaviors.	• Aggression can cause safety hazards which are not seen in the "heat of the moment."
	• Begins to show off.	• Showing off may counteract advances in other safety-related abilities.
5 Years	• Associative and cooperative play predominant. • Quarrels fewer but longer. • Aggression becoming hostile.	• Playground "busier" but also more contentious.
	• Often shows off.	• Strong counter-safety tendency.
6 Years	• Careful with property. • Can go about neighborhood independently with some degree of safety.	• Some safety problems lessened. • More self-control in group situations; cooperative interaction.

TABLE 4 - 1C
DEVELOPMENTAL MILESTONES:
COGNITIVE AND PERCEPTUAL DEVELOPMENT

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
18-24 Months	• Climax of sensorimotor period: inventing new means to ends.	• Beginning of experimentation: interest in new play patterns, including playground.
	• Casual thinking tied completely to here-and-now.	• Needs interesting, concrete activities; cannot plan abstractly about safety.
	• Attention "wanders:" attention span short.	• May not foresee obvious danger.
24-30 Months	• End of sensorimotor period. • Beginning of preoperational thought • Capable of internal thought and language.	• Remembers and understands rules.
	• Until 4 years: "preconceptual" thought. • Egocentricity. • Animism. • Artificialism. • Transducive reasoning. • Other problems with casual reasoning.	• Will get self into unsafe or dangerous situations unknowingly. • Will not know how to extricate self from dangerous situations.
	• Attention span still short.	• Gets distracted and may get caught in unsafe situations.
	• Selective attention is poor, but beginning to increase.	• May not be able to discern unsafe details from welter of items on playground.
3 Years	• Understands prepositions.	• May understand own body; spatial awareness better. • Able to solve simple problems.

TABLE 4 - 1C (continued)

AGE	SKILL	IMPLICATIONS FOR PLAYGROUND
4 Years	• Recognizes colors, shapes. • Concentrates more readily (may still have some selective attention and detail recognition problems). • Until 7 years: intuitive thought. • Causal reasoning better. • Still egocentric and centered in many situations. • Thought usually still not reversible; cannot realize potential implications of actions and figure out means of reversing situation.	• Building understanding of material world. • Will not wander to and from playground pieces; can still be distracted by sights and sounds; may not see the more subtle indicators of danger. • When in danger, at times, may still be unable to extract self.
5 Years	• Understands opposite analogies. Verbally more logical.	• Beginning to see many sides of problems, and to verbally come to solutions.
6 Years	• Defines words. • Less centered, egocentric. • Beginning to understand "real" causes of events.	• Could expect child to behave more safely on playground; to understand adults' directions well.

5. ANALYSIS AND DESIGN/USE RECOMMENDATIONS

5. ANALYSIS AND DESIGN/USE RECOMMENDATIONS

5.1 SURFACING

5.2 GENERAL HAZARDS

5.3 LAYOUT AND DESIGN

5.4 ASSEMBLY, INSTALLATION, AND MAINTENANCE

5.5 MATERIALS OF MANUFACTURE AND CONSTRUCTION

5.6 ACCESS AND PLATFORMS

5.7 TYPES OF EQUIPMENT

5.7.1 Slides

5.7.2 Swings

5.7.3 Climbing equipment

5.7.4 Merry-go-rounds

5.7.5 Seesaws

5.7.6 Spring rocking equipment

5. ANALYSIS AND DESIGN/USE RECOMMENDATIONS

The sections that follow present detailed consideration of the design and use issues for various types of playground equipment and features. The discussion is structured around the contents of the original (1981) two volumes of "A Handbook for Public Playground Safety", although the range of issues is broader here than in the earlier document.

Early in the project, a line-by-line review of the original Handbook was undertaken to identify every specific recommendation. Where possible, the rationale for each recommendation was researched and identified. Additional design and use considerations identified during analysis of the sources described in Section 2 were added to the set of issues identified in the Handbook. This overall set of design and use issues is what follows, organized around various types of hazards, equipment, or features.

A similar organization is used for discussing each of the design and use issues. The discussion begins with a description of the manner in which the issue was addressed by the original Handbook and the underlying rationale, if known. Following this is a detailed analysis of all the key issues, citing relevant data or treatment in any of the reviewed sources, including the technical literature, other standards and guidelines, accident/injury studies, the detailed incident analysis, and the observational study. Lastly, a formal recommendation and its rationale are presented.

One very important aspect of the analyses and recommendations concerns design criteria for children of different ages. While people of any age might use a playground, the range of typical expected users of public playground equipment can span from toddlers to 12-year-olds. The same set of design criteria will not always be acceptable for all age users. Unlike the original version of the Handbook, the recommendations developed here include separate treatment, where necessary, for preschool-age users and school-age users. Children at the younger end of the age range differ substantially from the others in their physical abilities and body dimensions, in patterns of equipment use, the types of play they engage in, and the kinds of injuries they typically sustain. Of course, physical, cognitive, and social changes occur continuously throughout childhood. Separation of the range of ages into two general groups, however, is broadly consistent with the settings and manner in which equipment tends to be used, as well as with major developmental considerations.

For design purposes, the two age categories are defined as 2 to 5 years old for preschoolers, and 4 to 12 years old for school-age children. The overlap between these groups is realistic in terms of playground equipment use, as well as reasonably conservative with respect to design criteria. Throughout this report, wherever there is a reference to "younger" users or preschool-age children, this should be taken to mean 2- to 5-year-olds. Wherever there is a reference to "older" users or school-age children, this should be taken to mean 4- to 12-year-olds.

5.1 SURFACING

5.1.1 REVIEW OF FALL INJURY DATA

5.1.2 EVALUATION OF IMPACT PERFORMANCE CRITERIA FOR SURFACES

5.1.2.1 Head impact injury
5.1.2.1.1 Parameters that affect magnitude of fall injury
5.1.2.1.2 Consequences of head impact
5.1.2.1.3 Functional brain damage vs. structural damage
5.1.2.1.4 Head impact responses of children
5.1.2.1.5 Biomechanical and fall characteristics of children and adults

5.1.2.2 Acceleration-based head impact criteria
5.1.2.2.1 Peak g
5.1.2.2.2 Wayne State Tolèrance Curve, Severity Index, and Head Injury Criterion
5.1.2.2.3 Limitations of head injury criteria

5.1.2.3 Recommendations for selection of a head injury criterion

5.1.3 EVALUATION OF THE 200 G CRITERION FOR PEAK HEAD ACCELERATION

5.1.3.1 Head injury criteria in standards and guidelines

5.1.3.2 Relationships among peak g, SI, and HIC

5.1.3.3 Test methods for measuring peak g

5.1.3.4 Recommendations for test method for impact attenuation performance of surfaces

5.1.3.5 Data on the impact attenuation performance of surfacing materials
5.1.3.5.1 Recommended depth of surfacing materials in standards and guidelines
5.1.3.5.2 Impact attenuation performance of surfaces in relation to injury to other body parts

5.1.3.6 Recommendations for the peak g criterion

5.1.4 OTHER CHARACTERISTICS OF SURFACING MATERIALS

5.1.1 REVIEW OF FALL INJURY DATA

Injury rates for falls from equipment. There is evidence that falls represent the most common mode of injury on playground equipment. In the NEISS-based Special Study of public playground equipment, falls to the surface accounted for 59% of all equipment-related injuries, and were the predominant mode of injury for each equipment type (Rutherford, 1979). In their discussions of 1982-86 Canadian CAIRE data and a Danish study by Christensen, Mikkelsen, Reich, and Krebs (1982), King and Ball (1989) reported that falls from a height were associated with 77% and 68% of all the playground-equipment related injuries, respectively. Contributing factors for falls from equipment will be discussed in connection with each major equipment type (see Section 5.7).

Injury patterns. In the 1978 NEISS data (Rutherford, 1979), head/facial injuries and arm/hand injuries each accounted for 39% of injuries resulting from falls to the surface. The majority (81%) of head and facial injuries could be classified as superficial, involving lacerations, contusions/abrasions, and avulsions; moreover, this was the most frequent type of injury that resulted from falls to the surface, accounting for 32% of the injuries. The results for serious head injuries were as follows: concussions, internal head injuries, and hematomas accounted for 12% of the head and facial injuries, while skull fractures, dislocations, and strains/sprains (e.g., sprained neck) represented 6%. By contrast, two thirds (67%) of injuries to the arm and hand consisted of fractures, dislocations, and strains/sprains; a fractured or dislocated arm was the second most common type of fall-related injury, accounting for 25% of all injuries. Only 32% of arm and hand injuries could be classified as superficial.

In summarizing the results of several British studies on playground equipment-related injuries, King and Ball (1989) stated that serious injuries attributed to falls from height typically involve the upper limbs and not the head. In their analysis of Australian injury data (Parry, 1982), King and Ball found that almost two thirds (34 out of 52 cases) of fractures caused by falling from a height were to the upper limb (including the hand and wrist), and that the majority of fractures caused by falls were sustained by children 8 years of age and older. Given these findings along with other injury data that they reviewed, King and Ball concluded that older children tend to use their arms to protect themselves when they fall. On the basis of New Zealand primary school accident data, Langley, Silva, and Williams (1981) reported that 39% of all injuries caused by falls from playground equipment consisted of upper limb fractures, whereas concussions accounted for 11% of the injuries.

In the detailed incident analysis of 1988 injury data, the most common type of injury resulting from falls to the surface was an upper limb fracture (44 out of 137 injuries due to falls), followed by superficial injuries to the head and face (38 out of 137 cases). Skull fracture, concussion, and internal head injury together accounted for 8 out of 137 injuries caused by falls. (Some victims sustained more than one type of injury in falls to the surface.)

Injuries as a function of impact surface. In his analysis of the 1978 NEISS Special Study data, Rutherford (1979) presented information on body location and type of injury due to falls to the surface as a function of type of surfacing material. Surfaces were classified as natural (including grass, bare earth, and rocky earth), protective (sand, gravel, wood chips, rubber matting, and other similar surfaces), and paved (asphalt, macadam, and concrete). Since there is much variation within the natural surfaces category, as Rutherford acknowledged, the following summary of results focuses on the more homogeneous categories of protective and paved surfaces. Injuries classified as severe included fractures, dislocations, strains/sprains, concussions, internal organ injuries, and hematomas; non-severe injuries included lacerations, contusions/abrasions, and avulsions. The rates of overall and severe injury to the head and face were higher for paved surfaces than for protective surfaces. The overall arm and hand injury rate was higher for protective surfaces than for paved surfaces. However, similar to the pattern observed for head and facial injuries, the proportion of upper limb injuries that were classified as severe was higher for paved surfaces than for protective surfaces.

In reviewing Rutherford's (1979) analysis of natural, protective, and paved surfaces, Butwinick (1980) pointed out that since surface depth was not taken into account, surfaces classified as protective were not necessarily deep enough to meet the current CPSC guideline for the minimum impact attenuation performance of surfacing materials. Butwinick suggested that the difference between injury rates for protective and other surfaces would have been more pronounced if the depth of material had been controlled. Based on NEISS in-depth investigations from 1972-1979, Butwinick examined the frequency of concussion and skull fracture associated with different types of impact surfaces. The majority (56 out of 75 cases) of concussions and skull fractures involved falls to the surface: 31 to paved surfaces, 18 to natural surfaces, 6 to semi-protected surfaces, and 1 unknown. Butwinick did not clarify the properties of surfaces that were classified as "semi-protected." As King and Ball (1989) pointed out, the effectiveness of resilient surfaces in reducing injuries has received very little systematic study. In their retrospective analysis of the head-first free falls of children, Mohan, Bowman, Snyder, and Foust (1978) noted that some of the children who fell onto less rigid surfaces such as lawns or wooden floors sustained much less severe injuries than those who fell from comparable heights onto concrete surfaces. They produced simulations of falls onto surfaces differing in stiffness which showed reductions in estimated peak accelerations experienced by the head in falls onto hard-packed soil and sand as compared to rigid surfaces, thus supporting Mohan et al.'s informal observations. Peak head accelerations associated with hard-packed soil were 30-50% of the values obtained for rigid surfaces; accelerations for sand impacts yielded even lower peak accelerations that were 15-22% of the rigid surface values. (See Section 5.1.2.2 for discussion of acceleration-based measures of impact attenuation.)

King and Ball (1989) cited a study by Christensen et al. (1982) in which severity of injury was examined as a function of type of impact surface. Cement, concrete, asphalt, iron, and stone were classified as non-shock absorbing; sand, woodchips, gravel, earth, and grass less than 8 inches in depth were considered to have intermediate shock absorbing properties, and sand greater than 8 inches in depth, rubber tiles, and pebbles were classified as highly shock absorbing. The percentages of minor, moderate, and severe injuries observed for the non-shock absorbing and intermediate surfaces were roughly comparable. For these two surface categories, from 56-60% and 30-34% of all injuries were reported as minor and moderate, respectively; one in ten injuries was reported as severe. Although none of the fall injuries associated with highly shock absorbant surfaces were classified as severe, too few data were available on this type of surface to justify any conclusions. Overall, these data had the following shortcomings: the method for defining injury severity and the body location of injury was not reported; the sample size was small; and, although the fall heights associated with these injuries ranged from about 1.5 to 6.5 feet, the effect of fall height was confounded with the effect of surface type.

The CPSC's death certificate records during the period from 1973-1977 show that 23 out of 36 fatalities involving public playground equipment were caused by falls, and that most of these deaths were caused by head injuries (Rutherford, 1979). Rutherford pointed out that more deaths were attributed to falls than to any other mode of injury.

5.1.2 EVALUATION OF IMPACT PERFORMANCE CRITERIA FOR SURFACES

In the current CPSC guidelines, the impact performance criterion for surfaces under playground equipment is intended to minimize the risk of serious head injury resulting from head-first falls. The nature of head impact injury is a broad problem, and has an extensive medical literature, but there is limited information of *direct* use for evaluating the current recommendation. It is beyond the scope of this report to review this very extensive literature. Therefore, this report will summarize only those points considered critical for evaluating the impact performance criterion. In addition, some head injury criteria that have been used to test protective headgear (e.g., football and motorcycle helmets) have not been applied directly to the playground situation. Although these criteria may have applicability to head injuries due to falls, they are not addressed here.

Major questions addressed in this and subsequent sections are as follows: 1) what is the rationale for using head injury as the basis for the impact performance criterion?; 2) what physical criteria are related to head injury, and how adequately do they predict the severity of head injury resulting from playground falls?; 3) what data are available on the impact-absorbing properties of surfacing materials, and what level of injury risk do the surfaces present?; 4) what other characteristics of surfaces must be taken into account in selecting an appropriate surfacing material?

Most existing models for predicting head injury severity, such as the peak g model for head injury recommended in the current guidelines, are based on measures of acceleration. Acceleration can be defined as the time rate of change of velocity, which can either be positive or negative (ASTM Standard Test Method F-355-86). The negative acceleration of a falling body on impact refers to the time rate of reduction of velocity, also known as deceleration.

Guideline content:

Volume 2 of the current guidelines states that the impact performance criterion for surfaces should be guided by head injury tolerance data for head-first falls of children. The suggested method for testing impact performance is the method developed by the National Bureau of Standards (NBS), which involves dropping an instrumented headform in guided free fall and measuring the peak acceleration response of the headform during impact. When tested in accordance with this procedure, "a surface should not impart a peak acceleration in excess of 200 g's to an instrumented ANSI headform dropped on a surface from the maximum estimated fall height." (Volume 2, 12.1, 12.2, 12.3)

Because hard surfacing materials such as concrete, asphalt, macadam, blacktop, etc. do not provide injury protection from accidental fall impacts, they are not recommended for use under playground equipment. Data reported by the National Recreation and Park Association (NRPA) (1976b), Beine and Sorrells for the NBS (1979b), and Roth and Burke (1975) indicate that hard surfacing materials do not meet the suggested 200 g criterion even for low velocity impacts. (Volume 2, 12.1, 12.4)

Probable rationale:

The justification for specifying an impact performance criterion for surfaces came from the the high proportion (59%) of all equipment-related injuries attributed to falls to the surface in the 1978 NEISS Special Study data. The rationale for basing the impact performance criterion on head injury rather than on some other type of injury can be found in the considerable proportion (39%) of fall injuries that involve the head (Rutherford, 1979), and in the potential severity of injury resulting from head impact. (NBS, 1979a; Rutherford, 1979)

In justifying its criterion for assessing the impact attenuation performance of surfaces, the NBS presented a brief review of the nature of head injury, particularly the consequences of head impact on a flat playground surface, and of data relating severity of head injury to physical measures of acceleration. When it impacts a surface, the head is subjected to an impulsive force, whose magnitude, direction, and duration depend primarily upon impact velocity, and on mechanical properties of the head and the surface. The impulsive force can cause deformation of the skull, linear acceleration of the head, rotation of the head with respect to the neck and torso, or some combination of these. Deformation of the skull can result in skull fracture and concussion, and deformation is usually accompanied by head acceleration. When the head strikes a resilient surface or a surface that consists of loose materials (e.g., sand), head acceleration can occur without significant skull deformation. Linear acceleration and head rotation may cause relative motion between the skull and brain, and changes in intracranial pressure; both of these effects can lead to concussion. (NBS, 1979a; Rutherford, 1979)

Due to the flatness of surfaces under playground equipment, linear skull fracture and/or concussion are more likely consequences of head impact than depressed skull fracture. Linear skull fractures involve failure of the overall skull, whereas depressed fractures involve localized failure of the skull due to the concentration of forces on a small area of the skull. In addition, most of the concussion tolerance data for humans were derived from linear skull fracture data. Therefore, the NBS used linear skull fracture data as the basis for their impact performance criterion. Peak acceleration was chosen as the criterion measure "because this greatly simplifies the testing procedure." Two studies were cited as justification for the recommended 200 g peak acceleration criterion. First, head-first drops of adult cadavers onto a flat surface showed that when the impact load was sufficient to cause skull fracture, peak accelerations were between 190 and 370 g's (Hodgson, Thomas, and Prasad, 1970). Second, head injury tolerance data for the head-first falls of children indicated that a conservative tolerance limit for head injury is 150-200 g average acceleration for 3 msec, or 200-250 g peak acceleration (Mohan et al., 1978). Based on these data, the NBS concluded that "the risk of serious head injury due to head-first fall is minimal when the peak acceleration imparted to the head is 200 g's or less." (NBS, 1979a)

The choice of test method (i.e., dropping an instrumented headform in guided free fall) was based on existing technology developed for evaluating the impact attenuation properties of protective headgear. The ANSI rigid headform was selected over other test headforms because "it is easily reproduced and has been shown to provide reasonably repeatable results." The magnitude of difference between the acceleration responses of the metal ANSI headform and the Wayne State University resilient or humanoid headform was reported to be about 20%, with the metal headform giving the higher accelerations. Therefore, the ANSI headform was chosen because it provides a more conservative estimate of acceleration response compared to the resilient headform, and because of the simplicity and reproducibility of its test apparatus. (NBS, 1979a)

The rationale for recommending that hard surfacing materials not be used under public playground equipment was stated in Volume 2 of the guidelines: data reported by the NRPA (1976), Beine and Sorrells in their study for the NBS (1979b), and Roth and Burke (1975) indicate that hard surfacing materials do not meet the suggested 200 g criterion even at low velocity impacts. For example, Beine and Sorrells reported that asphalt displayed a peak acceleration value of 400 g for a drop height of .43 foot. In addition, Rutherford (1979) reported that although paved surfaces (asphalt, macadam, and concrete) represented 10% of all playground surfaces in use, they accounted for about twice that proportion of all injuries due to falls.

5.1.2.1 Head impact injury

There are a number of reasons for using head injury data as the basis for the impact performance criterion. Although 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 mechanisms 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 heads. Thus, head injuries are more likely when children (12 years of age and under) fall 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 brain injury occurs during childhood, which involves periods of rapid brain development (Sweeney, 1979a). Finally, although severe upper limb injuries accounted for 27% of all injuries due to falls to the surface, a much higher percentage than that observed for severe head injuries (7%) (Rutherford, 1979), data are lacking on the characteristics of impact-absorbing surfaces that will reduce the risk of limb fractures. Other standards and guidelines are consistent in choosing impact performance criteria that attempt to minimize the risk of head injury.

The following sections briefly review the physical factors that influence the severity of a fall injury, the consequences of head impact, and the current state of knowledge about functional brain damage. To support the argument that children can be more susceptible to head impact injury as a result of falls than adults, data are presented on head impact responses of children, and on differences in biomechanical properties and fall characteristics of children as compared to adults.

5.1.2.1.1 Parameters that affect magnitude of fall injury

The severity of injury resulting from a fall depends on the following physical parameters: fall height, shape and rigidity of the impact surface and falling body, body orientation, and the body mass of the victim (Committee on Trauma Research, 1985; King and Ball, 1989; NBS, 1979a). Other relevant variables, such as acceleration of the falling body on impact, and duration of impact, can be expressed as functions of fall height and the nature of the impact surface and the falling body. Acceleration, in turn, influences the force on the impacting body, which is the product of the mass of the body and its acceleration (Newton's second law of motion).

Impact surface characteristics partially determine injury severity because energy-absorbing surfaces will deform upon impact, and thus provide a greater stopping distance for the falling body. As a result, acceleration and force on the impacting body will be reduced, and the duration of impact increased (Committee on Trauma Research, 1985; King and Ball, 1989). For example, given the same fall height, falls onto rigid surfaces result in shorter duration impacts than falls onto resilient surfaces. Shorter duration impacts are more likely to lead to injuries, except for very short duration impacts (less than 0.6 msec) (King and Ball, 1989). This is because more potential energy from a falling body will be transferred to an energy-absorbing surface than to a rigid surface, leaving less mechanical energy to be absorbed by the body; therefore, the potential for fractures and internal organ damage is reduced.

Body orientation and flatness of the impact surface together determine the contact area of impact. Given the same force on the impacting body, smaller contact areas lead to greater force per unit area, or stress, than larger contact areas. Thus, as King and Ball (1989) pointed out, "head first and feet first impacts will generally result in greater stress at the impact site (though not necessarily more severe injuries) than side first impacts."

In addition to the simple physical factors discussed above, other factors that influence the severity of fall injuries include the sex and age of the victim, his or her physical and mental condition, and his or her ability to distribute the impact forces effectively (Committee on Trauma Research, 1985; King and Ball, 1989). For example, defensive responses to a fall, such as extending the arms to break the fall or rolling over upon impact, can reduce the severity of impacts. Also, human tolerance to head impact varies both within and between individuals.

5.1.2.1.2 Consequences of head impact

Skull fractures can result from direct impact, whereas brain injury can be due to a combination of impact and acceleration. As Collantes (1989, draft) pointed out, impact and acceleration jointly cause head injuries in actual playground falls. In fact, when the head strikes a resilient surface, such as one consisting of loose materials, the impact force is distributed over a relatively large area, and head acceleration is likely to occur without significant skull deformation (NBS, 1979a). Because the types of playground surfaces that require evaluation consist primarily of non-rigid surfacing materials, such as sand, wood chips, and synthetic composites, this section will focus on head injuries likely to result from excessive head acceleration.

It is important to understand the relationship between the occurrence of skull fracture and brain damage or concussion. This is because, in the absence of adequate models for the functional and structural failure limits of brain tissues, current criteria for head impact tolerance 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 without 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).

In general, excessive head acceleration can lead to brain concussion and contusion, and rupture of associated blood vessels. In the case of head injuries caused by falls from playground equipment, both linear and angular accelerations produce head injuries. Both types of acceleration may cause relative motion of the brain with respect to the skull and changes in intracranial pressure; both of these outcomes can produce concussion (NBS, 1979a). Relative motion between the skull and brain occurs because "the scalp, skull, and brain do not all accelerate, decelerate or deform in unison" (Collantes, 1989, draft). When the skull decelerates during head impact, the loosely attached brain lags behind, causing deformation of brain tissues as the brain slams up against the skull at the site of impact and then rebounds back against the opposite side of the skull (Committee on Trauma Research, 1985).

Most current head impact tolerance criteria are based on linear acceleration as the dominant head injury mechanism, and do not take into account the effects of angular acceleration (King and Ball, 1989). Primate studies indicate that angular acceleration rather than linear acceleration is the cause of severe brain damage due to displacement of brain tissue (Goldsmith and Ommaya, 1984). Angular or rotational acceleration can lead to the following kinds of central nervous system damage: stretching of the neck ligaments, cervical cord, and brain stem (NBS, 1979a); shearing injuries to the brain, particularly in the midbrain, brain stem, and brain-skull interface region, which can lead to diffuse axonal injury and subdural hematoma (Goldsmith and Ommaya, 1984); and, gliding contusions due to excessive strains in cerebral blood vessels (Goldsmith and Ommaya, 1984).

5.1.2.1.3 Functional brain damage vs. structural damage

Physiological brain damage due to head impact is not necessarily accompanied by detectable structural damage except at the electron microscopic level. 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 tissues 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 visible sign of physical damage either to the skull or the brain, yet can lead to partial or complete loss of memory, or to disfunctions in motor, cognitive, and verbal skills (Collantes, 1989, draft).

The mechanisms of functional brain damage are less well established than those of anatomic or mechanical damage, which apply to skull fracture, brain hemorrhage, brain contusion, and brain tissue lesions. In reviewing the current state of knowledge about functional injury mechanisms of the brain, the Committee on Trauma Research (1985) reported that no data are available on the functional response and tolerance of the brain to linear and angular acceleration, and that technology for assessing functional injuries does not exist. Goldsmith and Ommaya (1984) pointed out that neural tissues and associated blood vessels form a complex and heterogeneous system, and that neither functional nor structural failure limits for the system as a whole, or for particular regions, have been firmly established. Small differences in the location, direction, or magnitude of an impact, as well as differences in the combination of linear and angular acceleration, can produce very different degrees of injury.

5.1.2.1.4 Head impact responses of children

Given that functional brain damage can occur at impact levels well below those produced by skull fracture or mechanical disruption of neural tissues, diagnosing brain injury can be difficult. As Winter (1988) noted in his review of playground equipment injuries in children, "there is no simple and reliable method for determining a patient's prognosis after craniocerebral trauma." The uncertainty involved in diagnosing brain injury can be even greater for child patients than for adult patients. In general, the clinical diagnosis of injuries in children is more difficult than for adults (King and Ball, 1989). Ward (1986) pointed out that the neurologic symptoms of brain injury vary to some extent as a function of the child's age: the younger the child, the more diffuse the symptoms tend to be, and the older the child, the more the symptoms resemble those found in an adult.

There is evidence that children can survive impacts from head-first falls which would be fatal to adults, and that they tend to recover sooner from head injuries than adults with comparable damage (Ball, 1988; Ivan, Choo, and Ventureyra, 1983; King and Ball, 1989; Mohan et al., 1978; Sweeney, 1979a). For example, in summarizing the results of studies conducted between 1977 and 1983 on mortality rates for severe head injury, Mayer and Walker (1985) reported that mortality in adult patients with severe head injuries ranged from 36-41%, in comparison to a 10-20% mortality rate in children with similar injuries. The more favorable outcomes of falls involving children relative to adults have been attributed to the lesser momentum of children's bodies in a fall and the greater flexibility of children's skulls (Ivan et al., 1983). However, other properties of children's head injuries suggest that children's susceptibility to head impact injury may have been underestimated.

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 increased risk of psychiatric disorders (Ball, 1988; King and Ball, 1989; Kraus, Fife, Cox, Ramstein, and Conroy, 1986; Mohan et al., 1978). Data based on modern brain-imaging techniques indicate that, in the absence of coma or fracture, even extensive neuronal damage can go undiagnosed (Ball, 1988). Ivan et al. (1983) concluded that childhood head injury may cause many subtle changes noticed by parents or teachers, and that these changes may only be detected with neuropsychologic testing. Symptoms may not always be immediately apparent: there is evidence of delayed reactions to head trauma, such as post-traumatic epilepsy (Mintz, 1974, cited in Sweeney, 1979a), and post-concussional syndrome which involves behavioral changes (King and Ball, 1989).

The long term effects of head injury in a child may be different from those in an adult, since the child's brain is still developing (Mohan et al., 1978). Based on a review of head trauma literature, Sweeney (1979a; 1979b) argued that interruption of normal neurological functioning during brain development can have serious and persistent effects. The risk of functional brain damage may be greater if head injury occurs in childhood than in adulthood (Sweeney, 1979a). In addition, the child's brain may be more susceptible to swelling following head impact than an adult's brain (A. King, personal communication, May 1989). Mayer and Walker (1985) found that children have a higher incidence of elevated intracranial pressure following severe head injury than adult patients do. Other differences between children and adults that support the greater susceptibility of children to head impact injury and fall injury are discussed in the following section. .

5.1.2.1.5 Biomechanical and fall characteristics of children and adults

Available data on human head impact tolerances are based primarily on frontal head impacts of healthy adult males and male cadavers; experimentally derived data on children are very limited (Ball, 1988; Committee on Trauma Research, 1985; Goldsmith and Ommaya, 1984; King and Ball, 1989; Mohan et al., 1978). Head impact tolerance levels for children are not necessarily similar to those for adults, particularly for head impacts resulting from falls. Biomechanical differences and differences in fall characteristics between children and adults suggest that children respond differently to falls and the resulting head impact.

The most relevant differences between children and adults concern properties of the skull and head. A child's skull is thinner than an adult's and so does not provide as much protection for the brain (Coln, 1985; King and Ball, 1989; Winter, 1988). The structure of the skull and the mechanical properties of skull bones also differ; Mohan et al. (1978) estimated that skull stiffness reaches 75% of adult stiffness between the ages of 6 and 9 years, although calcification of the skull continues until adulthood. A child's head is proportionately larger and heavier than an adult head; this fact, together with the younger child's less developed motor coordination, helps to account for the higher incidence of head-first falls in children than in adults (Coln, 1985; King and Ball, 1989; Mohan et al., 1978).

King and Ball (1989) reported the results of a study by Snyder, Foust, and Bowman (1977), in which actual free falls of children (12 years of age and under) and adults (20 years of age and older) were analyzed. Snyder et al. estimated initial or primary point of body contact with the impact surface. They found that, regardless of fall height, children tended to land on their heads after falling from a standing position and rotating during the fall onto their heads; adults tended to land foot or side first. However, as King and Ball pointed out, few of the fall heights were less than 9.8 feet, and so the data are not necessarily applicable to the lower fall heights that often characterize falls from playground equipment. Based on Snyder et al.'s (1977) data on free falls, King and Ball examined body location of injury as a function of age of the victim. Skull fracture and concussion were the predominant types of injury among 1- to 12-year-olds, together accounting for 58% of all child injuries, in comparison to 20% of all injuries among adults. By contrast, lower extremity fracture, the expected outcome of landing feet first, was more frequent among adults (23% of all injuries) than among children (15% of all injuries). The most common category of injury among adults was internal injury/spinal fracture, which represented 26% of all injuries in this age group, as compared to 12% of all injuries among 1- to 12-year-olds. The rate of upper extremity fracture was only slightly higher among adults (18% of all injuries) than among children (14%). Upper extremity fracture was more common among 7- to 12-year-olds than among children 6 years of age and younger, while skull fracture and concussion were more prevalent in the 1- to 6-year-old group than among older children. This finding is consistent with King and Ball's (1989) conclusion that older children tend to use their arms to protect themselves when they fall, whereas younger children lack the motor coordination to protect their heads in this manner (see Section 5.1.1). However, caution must be exercised in generalizing from Snyder et al.'s results due to limited sample size and the fact that impact conditions were reconstructed after the fact from medical information, subject interviews, and measurements at the accident site.

In summary, children tend to land head first when they fall, and so are at greater risk of head injury due to falls than adults. Given that the mechanisms of structural and functional brain injury are poorly understood, that functional brain damage is difficult to diagnose, and that even minor head injuries in children can have persistent effects, using head injury data as the basis for an impact performance criterion is justified. However, differences in the skull characteristics and head impact responses of children and adults indicate that head 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. The following section examines the limitations inherent in current head impact tolerance criteria in greater detail.

5.1.2.2 Acceleration-based head impact criteria

Sources of head injury data used to estimate human head impact tolerances include the following: anthropomorphic dummies, male cadavers, impact studies performed on anesthetized animals, computer simulation models, adult male volunteers exposed to low-level impacts, and studies of vehicle and falling accidents (King and Ball, 1989). Research on head impact tolerance has focused on conditions relevant to head impact trauma caused by vehicular collisions. Primate studies provide neurophysiological data on impact tolerance levels that are extrapolated to humans, and used in computer simulation models of linear head acceleration. Extrapolating data from sub-human primate studies to children is problematic, since it is difficult to match the physiological and chronological ages of humans and young animals (King and Ball, 1989). Head injury data are particularly limited for children.

One goal of head impact research has been to identify a simple physical measure that is correlated with the degree of head injury caused by an impact. Acceleration-based parameters are thought to be better predictors of head injury severity than energy-based parameters (e.g., energy absorbed by the head) (Ball, 1988; King and Ball, 1989; Mohan et al., 1978). As defined previously, acceleration of a falling body refers to the negative rate of change of the body's velocity on impact. Linear acceleration is the predominant criterion used to determine tolerance levels for skull fracture and brain injury.

The simplest acceleration-based measure is peak acceleration, known as peak g; peak g corresponds to the maximum acceleration experienced by the head upon impact with a surface. The current method for measuring peak g involves dropping a headform, equipped with a linear accelerometer, on its crown using a free fall apparatus to simulate the dynamics involved in a linear head impact. The CPSC guidelines recommend that a surface tested in accordance with this method should not impart a peak acceleration of more than 200 g to the instrumented headform. Three other models for predicting head injury severity are based on linear acceleration, but also take into account the duration of impact: the Wayne State Tolerance Curve (WSTC), the Severity Index (SI), and the Head Injury Criterion (HIC). Peak g, SI, and HIC, along with average acceleration (average g), are the head injury criteria currently used in various standards and guidelines for testing the impact attenuation performance of playground surfaces. One additional model that is based on a linear-acceleration model of head injury, the Mean Strain Criterion (MSC), measures the head deformation that results when impact forces are applied to various sides of the head; since the MSC is still under development it will not be discussed further.

Although a few surfacing standards are based on average g, this criterion is seldom addressed in discussions of head injury models. In their proposed safety standard for surfaces under equipment, the NRPA (1976a) concluded that average g more accurately predicts head injury severity than the peak g model. The NBS (1976) criticized the NRPA's technical rationale for choosing average g, on the grounds that the literature on head impact injury had been misunderstood and the mechanism of concussion resulting from impacts had been "misleadingly oversimplified." The NBS stated that "the average value of acceleration alone is a meaningless quantity." Given this negative assessment of average g by the NBS, and the fact that more recent head injury models like the SI and HIC are typically compared to peak g rather than to average g, the average g criterion is not considered further.

It is beyond the scope of this report to give detailed descriptions and comparisons of the head injury impact criteria (see Goldsmith and Ommaya, 1984; McElhaney, Stalnaker, and Roberts, 1973; Snyder, 1970). The following discussion focuses on those features of alternative head injury criteria that are of direct use in evaluating the adequacy of peak g as a predictor of head injury. Data relating severity of head injury and estimated risk of head injury to acceleration-based impact criteria are briefly reviewed, with primary emphasis on the few studies concerning head impact tolerances of children.

5.1.2.2.1 Peak g

As an extension of the free fall investigation by Snyder et al. (1977, cited in King and Ball, 1989) discussed previously (see Section 5.1.2.1.5), Mohan et al. (1978) analyzed the conditions of 30 head first, free (unimpeded) falls of children (1 to 10 years of age) onto mostly rigid flat surfaces (concrete, stone, and asphalt). Based on a computer simulation model, peak and average accelerations were estimated for 6 of the 30 head impacts, and these physical measures were compared with the severity of the actual head injuries. The Abbreviated Injury Scale (AIS) was used to categorize injury severity.

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 simple skull fracture and mild concussion; this is the minimum AIS rating for a skull fracture. Brain damage can be assigned AIS values between 3 and 6, depending on injury severity. An AIS value of 3 corresponds to severe, but reversible, damage; 4 signifies a serious, life-threatening injury that is potentially survivable; and 5 is reserved for critical injuries in which survival is uncertain.

Mohan et al. (1978) examined the severity of head injury produced by a fall as a function of impact velocity, fall height, peak g, and average g. Their major results can be summarized as follows. First, simple skull fractures and/or concussions (AIS = 2) are unlikely to occur for fall heights less than 3.3 feet, but are almost always expected for fall heights of 9.8 feet or higher. This finding is consistent with data reported by the CPSC (1974) on head injuries due to falls from high chairs: although head injuries accounted for about three quarters of all high chair-related injuries that required emergency room treatment, skull fractures represented only 2% of the total injuries. The majority of these high chair-related falls involved children 4 years of age or younger, and falls were typically from a height of 3.3 feet, thus supporting Mohan et al.'s conclusion that skull fracture seldom occurs for fall heights below 3.3 feet, at least for younger children (King and Ball, 1989; Mohan et al., 1978). Second, the tolerance limits for moderate head injuries, associated with an AIS value of 2, ranged between 200 and 250 g for peak head acceleration, and between 150 and 200 g for 3 msec average acceleration. Mohan et al. concluded that as long as impact accelerations are *below* these limits, children are unlikely to sustain serious head injuries (i.e., injuries that have an AIS rating of 2 or more). At the 200-250 peak g limit, falls are unlikely to result in more than a simple skull fracture or mild concussion (Butwinick, 1980).

Possible biases in these data, noted by Mohan et al. (1978), include the following: 1) the sample may have over-represented the stronger members of the population, possibly leading to overestimates of head injury tolerance limits; 2) information on concussion and amnesia was generally insufficient to determine the long term effects of head injury on the victim; 3) since most of the fall surfaces were rigid, injury tolerance values reflect head response to very short duration impacts. Because the risk of injury is typically greater for shorter duration impacts, using data from falls onto rigid surfaces would tend to bias the head injury tolerance limits toward more conservative values.

In addition to the Mohan et al. (1978) study discussed above, other impact studies using adult cadavers (e.g., Hodgson et al., 1970) have yielded data on peak g tolerance limits. However, since the emphasis here is on head impact tolerance data for children, these other studies are not addressed. (Refer to the *Probable Rationale* for the current CPSC guidelines on the peak g criterion in Section 5.1.2 for some data from the Hodgson et al. study.)

5.1.2.2.2 Wayne State Tolerance Curve, Severity Index, and Head Injury Criterion

Whereas peak g does not take into account impact duration, the Wayne State Tolerance Curve (WSTC) distinguishes between life-threatening and tolerable head impact injuries on the basis of both impact acceleration and duration. Although the WSTC is based in part on cadaver skull fracture tests, it is intended to predict the impact tolerance for adult human brain concussion in frontal head impacts against plane, unyielding surfaces (King and Ball, 1989). The WSTC assumes that the tolerance level for linear skull fracture is related to tolerance levels for brain concussion. In practice, because the type of acceleration parameter to be used was poorly defined, the WSTC proved difficult to apply to most head impacts. The WSTC was also criticized for the inadequate correlation of the physical parameters with data from living humans (Goldsmith and Ommaya, 1984; Mohan et al., 1978). However, the WSTC has served as the foundation for a biomechanical head injury criterion, and is used as a standard of comparison for more recent models.

The Severity Index (SI) was derived from the WSTC, and is applicable to the simple short duration impulses to the body generally associated with playground falls (King and Ball, 1989). 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).

The Head Injury Criterion (HIC) is an alternate interpretation of the WSTC, and is considered by many to represent the current state of the art (King and Ball, 1989). The portion of the impact pulse covered by the HIC was intended to take 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 U.S. Department of Transportation as the standard for evaluating head injury and testing safety systems (e.g., restraint systems) in the context of vehicular collisions.

After reviewing some objections to the HIC, Goldsmith and Ommaya (1984) concluded that much of the controversy surrounding this criterion "can be attributed to the impossibility of providing an analytically rigorous, yet conceptually simple criterion for a phenomenon of incredible complexity with the added factor of the variability of the mechanical properties of human head tissue." Considering that all current head injury criteria are based on oversimplified models of limited conditions and types of head impact injury, this statement is applicable to other criteria as well.

5.1.2.2.3 Limitations of head injury criteria

Since both the SI and HIC were based on the WSTC, they share certain critical properties and limitations with the WSTC. As a class, these models assume that linear acceleration is the dominant head injury mechanism and do not take into account brain injury due to angular acceleration. Head injuries associated with falls from playground equipment result from a combination of linear and angular acceleration loads to the head. In addition, these criteria are intended to predict the severity of head injury resulting from *frontal* head impacts. However, given the same impact force, head injury severity can vary as a function of which region of the head is subjected to loading. Different parts of the human skull have different force-deflection characteristics, and brain motion in one direction may result in more severe injuries than in other directions (Goldsmith and Ommaya, 1984; Mohan et al., 1978). Therefore, an adequate head injury criterion should take into account regional differences in head impact response.

A major shortcoming of WSTC, SI, and HIC, is that although they are intended to predict the severity of concussion (WSTC) or internal brain injury (SI and HIC), they have not been correlated with the risk or severity of brain damage, particularly for children (Committee on Trauma Research, 1985; King and Ball, 1989; Goldsmith and Ommaya, 1984). As Collantes (1989, draft) pointed out, these criteria do not distinguish between skull and brain injury tolerance. This is a serious limitation given that tolerance levels for brain injury are well below those for skull fracture, and that functional brain damage can occur well before noticeable structural failure of brain tissues. The Committee on Trauma Research (1985) concluded that current techniques based on measuring acceleration responses of the head "are not sufficient to assess the risk of severe and moderate injury to the brain with confidence." The problem is exacerbated when these criteria are applied to head injury in children, since the threshold values are based primarily on data from primates and human adults, who respond differently to head impact than children (King and Ball, 1989).

The peak g criterion is subject to some of the same limitations as the WSTC, SI, and HIC. Peak g does not take into account angular acceleration as a mechanism of head impact injury, or impact location. Moreover, peak g tolerance limits are based on linear skull fracture data, and their correlation with the risk of brain injury has not been adequately established.

5.1.2.3 Recommendations for selection of a head injury criterion

There is much uncertainty associated with predicting the amount of force the human head can tolerate during impact before injury occurs (Collantes, 1989, draft); the uncertainty is even greater when assessing head impact injury in children. Regardless of the head injury criterion used, any one tolerance limit will not discriminate between the absence and onset of head injury, or between safety and danger. As King and Ball (1989) pointed out, there will always be some risk of injury or death associated with playground falls.

Although the SI and HIC have the advantage of taking into account the duration of the impact pulse, there is consensus that these measures have some of the same fundamental shortcomings as the peak g criterion. There is also the practical consideration that the peak g criterion 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).

Therefore, it is recommended that peak g be maintained as the physical criterion for predicting the risk of head injury, acknowledging the following caveats. First, no single measure can take into account all the critical factors that determine the severity of head injury. Different types of head injury (i.e., those resulting from different locations of impact or directions of loading) may be associated with different tolerance limits. Second, neither the peak g criterion nor other current head injury criteria assess the ability of surfaces to minimize the risk of other types of severe injuries that result from playground falls, the predominant type being limb fracture (see Section 5.1.3.5.2). The limitations associated with peak g, particularly those related to differences in the head impact responses of children and adults (for whom the measure was intended), can be offset to some extent by selecting a conservative value for the peak g tolerance limit.

5.1.3 EVALUATION OF THE 200 G CRITERION FOR PEAK HEAD ACCELERATION

The purpose of this section is to evaluate the 200 g peak acceleration criterion recommended in the CPSC guidelines as the tolerance limit for head injuries experienced by children in playground falls. Head injury criteria in current standards and guidelines, estimates of head injury risk associated with these criteria, test methods for measuring peak g, and data on the impact attenuation properties of surfacing materials are reviewed in the following sections prior to making a recommendation for the maximum allowable peak head acceleration.

5.1.3.1 Head injury criteria in standards and guidelines

A concept central to evaluating the impact attenuation performance of playground surfaces is that of critical height. Current standards generally specify that when a headform is dropped onto a test surface, in accordance with some test procedure, the peak g, SI, or HIC should not exceed a criterion value; the maximum drop height at which this criterion value is reached is referred to as the critical height of the surface being tested. The vertical distance between the highest accessible part of the equipment and the underlying surface should not be permitted to exceed the critical height of the surfacing material (King and Ball, 1989). Upper limits for head injury criteria specified in current standards and guidelines are presented below. Note that in some cases, the ASTM Standard Test Method for Shock-absorbing Properties of Playing Surface Systems and Materials (F-355-72; F-355-78; F-355-86) is designated as the test procedure, and the ANSI C rigid headform (ANSI Z 90.1-1971) is designated as the test headform. In cases where the test missile is unknown, direct comparisons of head injury criteria specified in different standards may be misleading.

<u>Peak g = 250</u>

- New Zealand standards (NZS 5828: Part 1: 1986): ASTM F-355-78, Procedure B (uses hemispherical missile); specify SI of 1000 as alternate criterion.

<u>Peak g = 200</u>

- Current CPSC guidelines: ANSI C headform
- ASTM draft standard for impact attenuation of surface systems under and around playground equipment (8th draft, 1989): ASTM Test Method F-355, Procedure C (uses ANSI C headform)
- Seattle draft standards (1986); specify that surface under playground equipment must be able to absorb an impact acceleration rate <u>in excess of</u> 200 g's to the head, for a fall height of 10 feet.

<u>Peak g = 150-200</u>

- TUV in West Germany (Nagel and Mosch, 1986, cited in King and Ball, 1989)

Average g = 50

- o U.S. Franklin Institute Research Laboratories (reported by the NRPA, 1976b): ASTM F-355-72, Procedure B (uses hemispherical missile)

Average g = 30

- o Sweden (Christensen et al., 1982, cited in King and Ball, 1989)

HIC = 1000

- o Dutch Instituut TNO (Holierhock and Kooi, 1988, cited in King and Ball, 1989)

SI = 1000

- o New Zealand standards (NZS 5828: Part 1: 1986): ASTM F-355-78, Procedure B (uses hemispherical missile); specify peak g of 250 as alternate criterion
- o British draft safety standards (BSI draft standard, 1987/88, cited in Ball, 1988; King and Ball, 1989); headform is metal hemisphere
- o Australian draft safety standards (Standards Association of Australia, 1988, cited in King and Ball, 1989)

5.1.3.2 Relationships among peak g, SI, and HIC

To evaluate whether 200 g is sufficiently conservative as an upper limit for peak head acceleration, it is informative to compare this criterion to other currently accepted head injury tolerance limits. The level of head injury risk associated with playground falls is determined by the upper limit of peak g, SI, or HIC that is chosen as the impact attenuation criterion. As King and Ball (1989) pointed out, if the critical height of a playground surface satisfies an SI value of 1000, it is statistically safer than one that satisfies an SI value of 1500, and less safe than one determined by an SI of 750. The comparison of head injury criteria in current standards and guidelines, presented above, indicates that different standards organizations have adopted different levels of risk. Data are available on degree of injury risk associated with different HIC and SI values.

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, respectively; about 10% of the population would experience such injuries at an SI value of 1000. For a given HIC value, the percentage of the population expected to have a skull fracture (AIS = 2) was virtually the same as the percentage expected to sustain life-threatening brain injury.

A similar function relating peak g to risk of brain injury is not available because, compared to HIC or SI, "its scientific basis as a measure of brain injury tolerance is less sound" (King and Ball, 1989). SI and HIC are roughly comparable for the types of simple impact expected to result from head first falls onto flat playground surfaces. Although HIC and SI cannot be compared directly to peak g, a number of observations can be made about their relationship to peak g (King and Ball, 1989). First, for most playground surfaces tested, an SI of 1000 is thought to be roughly equivalent to peak g values between 150 and 200 g. However, because peak g does not take account of impact duration, there are cases where a peak g of 200 could be equivalent to HIC or SI values considerably above 1000, and thus associated with a higher, and possibly unacceptable, risk of serious brain injury. Mohan et al. (1978) also noted that small changes in peak g can be associated with large changes in HIC. However, comparisons among peak g, HIC, and SI are dependent on the test missile and type of surfacing material.

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 200 g there is 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. Given this assessment, the German TUV (Nagel and Mosch, 1986, cited in King and Ball, 1989) chose an upper limit of 150-200 g rather than the more conservative 50 g value because, in practice, they expected body reactions to head-first falls (e.g., breaking a fall with outstretched limbs) to reduce the severity of impacts. However, as discussed previously, younger children are less capable than older children of using their limbs to break a fall; older children can reduce the risk of head injury by using such a defensive strategy, but only at the cost of increased risk of long bone fractures. Neither the peak g criterion, the SI, nor the HIC addresses the effectiveness of surfaces in reducing the risk of limb fractures (see Section 5.1.3.5.2).

An additional consideration in choosing an upper limit for peak g is that cost and design restrictions will tend to increase as the peak g limit decreases (King and Ball, 1989). Data on the impact attenuation performance of surfacing materials support the idea that currently available surfacing materials can satisfy peak g criteria more conservative than the CPSC's recommended peak g value of 200, at fall heights up to 10 feet (see Section 5.1.3.5). However, the study by Mahajan and Beine (NBS, 1979a) on which these data are based is subject to limitations that are discussed in Section 5.1.3.5.

5.1.3.3 Test methods for measuring peak g

Most standards that specify a head injury criterion require that the impact attenuation performance of surfacing materials be tested by dropping an instrumented headform in guided free fall from different drop heights. Impact attenuation has been defined as "the ability of a surface system to reduce and dissipate the energy of an impacting body" (ASTM draft standard for impact attenuation of surface systems under and around playground equipment, 8th draft, 1989). There is currently no internationally agreed test method; although different laboratories use similar measurement methods, discrepancies in methodological details have produced some variability in test results (King and Ball, 1989). For example, King and Ball recognized that, until recently, the draft British standard for testing playground safety surfacing (1987/88) did not define the test method stringently enough to ensure reproducible results.

As noted previously, the New Zealand standard (NZS 5828: Part 1: 1986) and the ASTM draft standard for impact attenuation of surface systems under and around playground equipment (8th draft, 1989) require that the shock absorbancy of surfacing materials be tested in accordance with ASTM Standard Test Method F-355. (For brevity, the ASTM draft standard is also referred to as the ASTM draft standard for playground surface systems.) Surfacing tests performed by the Franklin Institute, which served as the basis for the NRPA's proposed safety standard (1976b), conformed to ASTM F-355-72 (see Section 5.1.3.1). However, ASTM F-355 includes three different procedures (Procedures A, B, and C), corresponding to three types of missiles that differ in mass and geometry. The New Zealand standards and the Franklin Institute adopted Procedure B, which uses a missile with a hemispherical, metal impacting surface; this hemispherical missile weighs 15 lbs. The ASTM draft standard for playground surface systems (8th draft, 1989) specifies Procedure C, which uses the ANSI C magnesium alloy headform (weight equal to 11 lbs); the mass and geometry of the headform are specified in ASTM Test Method F-429-79. Procedure C requires the headform to be positioned so that all impacts occur on the crown. The CPSC guidelines suggest that the impact performance of surfacing materials be tested in accordance with the method developed by the NBS (1979a), which employs the ANSI C headform.

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 ANSI C headform and other rigid headforms (i.e., metal or wood) produce higher acceleration values and thus provide more conservative estimates of head impact response, as compared to a resilient headform (King and Ball, 1989; NBS, 1979a). However, this effect of using a rigid headform is less pronounced in tests of non-rigid surfaces than in tests of rigid surfaces. Since the rigid hemispherical missile specified in Procedure B of ASTM F-355-86 is 4 lbs heavier than the ANSI C headform, it is also associated with higher acceleration values and may underestimate the shock-absorbing properties of surface materials with regard to head-first impact (Collantes, 1989, draft). Thus, differences in the characteristics of test headforms may account in part for discrepancies among reported test results.

The ASTM Standard Test Method F-355-86 includes specifications for the test apparatus, recording equipment, conditioning of test samples for a minimum of 4 hours (e.g., relative humidity, temperature, storage conditions between tests), test procedure (e.g., time intervals between successive drops), and calculation of maximum acceleration (peak g), SI, and several optional parameters such as maximum penetration and dynamic hardness index of the surface system. For each test condition (e.g., combination of drop height and sample temperature), at least two specimens should be tested; three consecutive drops are made and the average of the peak g recorded for the second and third drops is calculated. For other details of this test methodology, the reader is referred to the documentation for ASTM F-355-86.

Although the ASTM draft standard for playground surface systems (8th draft, 1989) requires that surfacing samples be tested according to ASTM Standard Test Method F-355, it contains additional specifications. For example, laboratory samples must be preconditioned for a minimum of 24 hours prior to testing, and, at each drop height, surfacing samples must be tested at 30, 72, and 120 degrees F. Although ASTM F-355-86 addresses the testing of surfacing samples at temperatures other than the recommended 72 degrees F., it does not stipulate what those temperatures should be. 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). It seems reasonable that surfacing tests should be conducted at a range of temperatures to ensure that test results can be generalized to use in a variety of climates. Because the test methodology is more strictly defined in the ASTM draft standard for playground surface systems than in previous test methods, it is likely to yield more reproducible results.

A critical feature of both the NBS test method and the ASTM draft standard for playground surface systems (8th draft, 1989) is that during each series of consecutive drops (three drops in the ASTM method, and two drops in the NBS method), the test sample is left undisturbed. This is particularly important in the case of loose surfacing materials (e.g., sand, wood chips), since the first drop is likely to leave a depression in the surfacing material where it has been displaced and compressed. As a result, the second and third drops are made onto a surface of lesser depth, which may produce higher peak acceleration responses of the test headform. Evidence for this effect was presented by Mahajan and Beine (NBS, 1979a). Since loose materials are routinely displaced by activities like running and jumping, leaving the test sample undisturbed during a series of drops more accurately represents the actual use conditions of loose surfacing materials on playgrounds.

In recent round robin tests conducted by the ASTM F08.52.01 Task Group (1989), in accordance with an earlier ASTM draft standard for playground surface systems (7th draft, 1988), an attempt was made to simulate the compaction of materials that occurs under actual playground conditions. Test samples of wood fiber at the requisite depth were compacted prior to testing by having someone walk or stand on the loose materials in their container; after compaction, additional material was added to restore the test depth. Preliminary testing of surfacing materials by the CPSC has also incorporated a procedure for compressing loose materials (e.g., wood fiber) prior to the drop tests (J. Preston, personal communication, October 1989). In addition, the ASTM draft standard for playground surface systems (8th draft, 1989) contains specifications for a field test procedure; such on-site testing would more accurately represent the impact performance of loose materials under conditions of actual use.

5.1.3.4 Recommendations for test method for impact attenuation performance of surfaces

It is recommended that the ASTM draft standard for the impact attenuation of surface systems under and around playground equipment (8th draft, 1989) be adopted as the standard method for testing the impact attenuation performance of playground surfaces. Because the ASTM draft standard more stringently controls for important sources of variability related to the conditioning of surfacing samples and the timing of test drops, it ensures more reproducible results than the NBS test procedure recommended in the current guidelines (NBS, 1979a). Specifications for this test methodology can be found in the documentation for the ASTM draft standard for playground surface systems.

5.1.3.5 Data on the impact attenuation performance of surfacing materials

Test results on the impact attenuation performance of surfacing materials are difficult to compare across studies because of differences in the test procedures and head injury criteria used, and because categories of surfacing materials (e.g., gravel, bark, chips) are often not clearly defined and their depth may not be specified. The primary source of data reviewed in this section is the Mahajan and Beine study for the NBS (1979a) which did not use the ASTM Standard Test Method F-355, and is also subject to other limitations. It should be noted that the CPSC is collecting new data on the impact performance of commonly used surfacing materials at different material depths, and from drop heights up to about 12 feet; the tests are to be conducted in accordance with the ASTM draft standard for the impact attenuation of surface systems under and around playground equipment (8th draft, 1989). Therefore, the conclusions reported here may require modification when the new data become available.

The study conducted by the Franklin Institute, which was presented as the supporting rationale for the NRPA's proposed safety standard for surfacing materials (1976b), used average g rather than peak g as the head injury criterion. Therefore, these data cannot be directly compared to data on peak g performance that are most frequently reported in other studies; this difference in the choice of the acceleration-based parameter has been the source of some confusion in the literature. The Franklin Institute test results have been widely cited. They are used as supporting rationale for surfacing requirements in the British standards (BS 5696: Part 3: 1979), and are cited in Esbensen (1987). One manufacturer's catalog includes surface impact test results that appear to be based on the Franklin Institute data. However, the Franklin Institute test results could easily be misconstrued as peak acceleration values. For example, when King and Ball (1989) reported the 50 g head injury tolerance limit adopted by the Canadian Institute of Child Health (1985) and the Franklin Institute, they presented this value as a more conservative limit than the 200 peak g value, but did not identify it as an average acceleration measure.

<u>Loose surfacing materials and unitary synthetic materials</u>. In their evaluation of the adequacy of NRPA's proposed safety standard, Beine and Sorrells (NBS, 1976b) concluded that the test data submitted by the Franklin Institute were "incomplete, apparently erroneous, and statistically inconclusive, and hence inadequate." NBS recognized the need to develop a methodology for evaluating the impact attenuation performance of surfaces with regard to minimizing the risk of head injury. To address this need, Mahajan and Beine (NBS, 1979a) proposed and implemented a methodology for testing surfaces, recommended the 200 g peak acceleration criterion on the basis of head injury data, and reported peak g values as a function of impact velocity for different surfacing materials. The surfaces they tested included sand, shredded tire, gravel, pine bark nuggets, shredded hardwood bark, cocoa shell mulch, crushed stone, rubber mats, and synthetic turf. The results of this laboratory study represent the most comprehensive data to date on the impact-absorbing properties of surfacing materials.

Mahajan and Beine (NBS, 1979a) tested surfaces of different thicknesses (4- and 6-inch depths for loose surfacing materials), under both wet and dry surface conditions, at drop heights up to 9.7 feet. Their major results can be summarized as follows: 1) in general, wet surfaces were associated with lower peak g values than dry surfaces; 2) with the exception of gravel, thicker surfaces tended to provide better impact attenuation than thinner surfaces; 3) most loose materials performed better than unitary materials (i.e., outdoor rubber mat, indoor gym mat, synthetic turf).

Under dry conditions, at a material depth of 6 inches, pine bark mini-nuggets, pine bark nuggets, and crushed stone displayed peak acceleration values around 100 at the maximum drop height (about 10 feet); under the same conditions, shredded tire displayed a peak g of about 110, and the peak g values for both sand and shredded hardwood bark did not exceed 150. Thus, all loose surfacing materials tested, with the exception of gravel and cocoa shell mulch, satisfied a peak g criterion of 150 at a drop height of 10 feet. Mahajan and Beine (NBS, 1979a) found that impact attenuation performance can change abruptly as impact velocity increases, and cautioned against extrapolating performance data to higher impact velocities (or fall heights) than those actually tested.

Several shortcomings of Mahajan and Beine's (NBS, 1979a) study have been discussed in the literature. Werner (1980) commented that loose materials should have been tested under conditions of a playground environment, as soils were in the impact attenuation study by Beine and Sorrells (NBS, 1979b). Beine and Sorrells also noted that the loose materials in Mahajan and Beine's laboratory study were not subjected to compaction, aging, or other conditions of playground exposure. Therefore, the attenuation performance of these materials is most likely better than if they had been tested under actual playground conditions. Mahajan and Beine did recognize that loose materials are displaced during normal playground use, thus reducing their thickness and impact-absorbing effectiveness, and recommended that loose materials be installed "in sufficient thickness to reduce the effects of casual jumping and running." Butwinick (1980) pointed out that gravel was not clearly defined; the report specified a 3/8-inch mesh size. Additional properties of gravel such as shape (rounded or angular), uniformity of size, and source (unscreened river gravel or river washed) are specified in current guidelines and standards (see Section 5.1.4).
In their discussion of impact attenuation data, King and Ball (1989) noted the wide variation in performance of unitary synthetic materials. They attributed this variability to two sets of factors: 1) there is a wide range of materials and designs that comprise unitary synthetic materials (e.g., sectional rectangular rubber matting, synthetic turf with a urethane base, urethanes that are poured in place); 2) the ability of synthetics to absorb impact depends on such factors as the volume of air within the basement air cells, the thickness of the surface layer, and the type of undersurfacing used.

Asphalt and concrete. There is evidence that even for fall heights as low as 5 to 12 inches, asphalt and concrete display peak g values between 250 and 400 (Roth and Burke, 1975; NBS, 1979b). Critical fall heights reported for concrete and asphalt surfaces range from 4 inches to 3.3 feet, depending on the head injury criterion adopted (King and Ball, 1989). Lower critical heights are associated with the use of rigid headforms in drop tests, whereas higher critical heights are based on fall data for children (Mohan et al., 1978; CPSC, 1974) (see Section 5.1.2.2.1). There is consensus in the British (BS 5696: Part 3: 1979), New Zealand (NZS 5828: Part 1, 1986), Canadian draft (CAN/CSA-Z614, 1988), and Seattle draft (1986) standards, and in the Play For All Guidelines (Moore et al., 1987) that asphalt, concrete, and similar hard surfacing materials are unsuitable for use under playground equipment. The German standards (DIN 7926: Part 1, 1985) specify that the maximum free height of fall permitted for concrete and stone surfaces is 3.3 feet; free height of fall is defined in the German standards as the vertical distance between an accessible part of playground equipment intended for playing and the underlying surface.

Soil and hard-packed dirt. The impact-absorbing effectiveness of soils depends on the amount of air trapped between individual particles, which is in turn influenced by climatic conditions, (King and Ball, 1989). Hot sun and low precipitation, or, at the other extreme, long periods of excessive rain, high humidity, and frost can reduce the cushioning potential of soils, even though some increases in moisture can improve attenuation performance. King and Ball (1989) reported wide differences among standard organizations in the maximum permissible fall heights recommended for earth surfaces: whereas the Dutch Instituut TNO (Holierhock and Kooi, 1988) reports critical heights from 5 to 8 feet (HIC = 1000), the Adelaide draft standard (1988) from Australia cites a critical fall height of 12 inches (SI = 1000), and the Canadian Institute of Child Health (1985) does not recommend the use of earth surfaces.

Grass and turf. The following factors argue against the use of grass under playground equipment: given sufficient wear and tear, grass will die, and the resulting ruts can be hard and dangerous; grasses differ in their ability to withstand wear and to regrow after being damaged; and, formerly grassy areas can turn to mud in wet weather (Moore et al., 1987; British standards; New Zealand standards). Excessive wear and muddy conditions will considerably reduce the cushioning effectiveness of grass surfaces. The Play For All Guidelines states that grass is unsuitable as a fall-absorbing surface under equipment; the New Zealand standards prohibit its use under fixed equipment or under equipment that receives high use, although it is permitted under low portable equipment (low equipment height is not defined).

5.1.3.5.1 Depths of surfacing materials recommended in standards and guidelines

As discussed above, thicker surfaces tend to provide better impact attenuation than thinner surfaces (NBS, 1979a). In a study by Hodgson (no date), 6 inches and 8 inches of wood fiber performed about equally for drop heights of 6 feet or less. However, for drops of 10 feet, the peak g response of the headform was about 16% lower for the 8 inch depth (100 peak g) than the 6-inch depth (120 peak g). At a 10-foot drop height, increasing the depth of materials to 12 inches produced about a 40% reduction in the peak g response below what was observed in the 8-inch condition. The peak g value of 60 displayed by wood fiber at a 12-inch depth (for the 10-foot drop height) is close to the 50 g limit associated with a very low risk of permanent brain injury resulting from a head first fall (King and Ball, 1989). Considering these data, and the fact that loose surfacing materials are displaced and compacted during normal playground use, thus reducing their cushioning potential, the minimum depth of loose materials should represent a conservative value.

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 strong consensus in standards and in the literature that a more conservative depth is warranted. Researchers do not typically distinguish among various types of loose surfacing materials when making recommendations for depth; loose surfacing materials include noncompacted sand, gravel, bark, tanbark, bark nuggets, bark mulch, crushed stone, and chopped tire.

Recommendations for minimum depths range between 8 and 12 inches, but 10- to 12-inch and 12-inch depths were frequently suggested (Aronson, 1988; Beckwith, 1988; Esbensen, 1987; Frost, 1986b; Goldberger, 1987; Goldfarb, 1987; Lovell and Harms, 1985; Moore et al., 1987; Sweeney, 1980, 1982). When shredded or chopped tires were addressed separately from other loose materials, recommended minimum depths ranged between 4 and 8 inches (Beckwith, 1988; Moore et al., 1987). Beckwith suggested that in impact zones under swings and slide chute exits, loose materials should be installed at a minimum depth of 24 inches.

Depths of loose materials specified in various standards also range between 8 and 12 inches. The New Zealand (NZS 5828: Part 1, 1986) and British standards (BS 5696: Part 3, 1979) both require at least 8 inches of gravel and 12 inches of sand. The New Zealand standards specify that shredded pinebark and similar materials (shredded bark chips, wood chips) should be at least 8 inches deep on low-use and moderate-use playgrounds. The Seattle draft standards recommend 12 inches for sand or appropriate substitutes (gravel, shredded tires). Although the German standards require a minimum 8 inch depth for sand and fine gravel, they state that the materials should be installed at an initial depth of 16 inches to offset dispersion effects.

5.1.3.5.2 Impact attenuation performance of surfaces in relation to injury to other body parts

In the 1978 Special Study (Rutherford, 1979), severe upper and lower limb injuries together accounted for 37% of all injuries due to falls to the surface, whereas severe head injuries were much less commonly implicated (7% of all injuries). However, data are not available on the effectiveness of surfaces in reducing the risk of severe injury to the limbs or the neck specifically. Because loose surfacing materials are displaceable, they conform to the shape of the impacting body; this would tend to increase both the area and the duration of impact, which reduces the risk of injury. Therefore, loose surfacing materials may provide protection against severe injuries to the limbs and neck. Although this potential mechanism for impact attenuation has not been studied systematically in relation to playground falls, it may provide additional justification for recommending more conservative depths for loose surfacing materials.

5.1.3.6 Recommendations for the peak g criterion

Further research is needed to determine the appropriateness of the current 200 peak g criterion in the CPSC guidelines. Fundamental limitations and uncertainties associated with the peak g model for head injury and with the 200 peak g criterion include the following:

- o The peak g model does not take into account the effects of impact duration, angular acceleration, impact locations other than frontal head impact, and directions of impact other than the anterior-posterior direction associated with frontal head impact.

- o The peak g model has not been correlated with the risk of structural or functional brain damage, particularly for children.

- o 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.

- o 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.

Due to the lack of adequate data on the head impact responses of children under conditions associated with falls from playground equipment, a change in the 200 peak g criterion is not warranted at the present time, although the above limitations and uncertainties are recognized. Therefore, a surface should not impart a peak acceleration in excess of 200 g to an instrumented ANSI headform dropped on a surface from the maximum estimated fall height, when tested in accordance with the ASTM draft standard for the impact attenuation of surface systems under and around playground equipment (8th draft, 1989). However, it should be emphasized that using a peak g criterion that is lower than the recommended value will further reduce the risk of serious head injuries resulting from falls. Available data from the Mahajan and Beine study (NBS, 1979a) on the impact attenuation performance of playground surfaces suggest that a peak g value more conservative than the recommended 200 peak g criterion is achievable.

Hard surfacing materials such as asphalt and concrete are unsuitable as fall-absorbing surfaces under playground equipment. Even at fall heights under 12 inches, these hard surfacing materials have displayed peak acceleration values in excess of 250 g. Earth surfaces such as soils and hard-packed dirt are also not recommended for use under playground equipment, because their attenuation performance can vary considerably depending on climatic conditions related to moisture and temperature. Similarly, grass and turf are not recommended as fall-absorbing surfaces under playground equipment, because their effectiveness can be reduced considerably due to wear and muddy conditions.

Currently available surfacing materials, installed at depths from 6 to 12 inches, have satisfied a 200 peak g criterion as well as a 150 peak g criterion at fall heights up to 10 feet. These materials include sand, pine bark nuggets, pine bark mini-nuggets, shredded hardwood bark, wood fiber, crushed stone, and shredded tires. However, most of these test results were taken from the Mahajan and Beine study (NBS, 1979a), which did not use the recommended ASTM draft standard for playground surface systems. In addition, characteristics of a given type of material, such as the size and shape of loose particles, and its depth, can significantly affect its fall absorbing potential.

It is recommended that loose surfacing materials be maintained at a minimum depth of 12 inches, rather than at the minimum depth of 6 inches currently recommended by CPSC. The 12-inch minimum depth takes into account other factors besides the impact attenuation performance. It helps to compensate for the lack of adequate data on the impact attenuation performance of surfaces, and for the fact that most available impact data probably overestimate the attenuation performance of loose surfacing materials since tests did not simulate the displacement and compaction of materials that occurs under actual playground conditions. In addition, there is some indication that increasing the depth of loose materials may help to reduce the risk of severe injuries to body parts other than the head, such as the upper limbs and neck; this is important because these types of severe injuries are not addressed by the peak g criterion. In heavily used impact zones such as those under swings and slide chute exits, where displacement and compaction of materials will be most pronounced, loose materials should be maintained at greater depths.

Generalizations about the impact attenuation performance of unitary synthetic materials cannot be made, because they constitute a rapidly developing range of products that vary considerably in composition and design.

The above recommendations for the 200 peak g criterion and minimum depth of loose surfacing materials represent minimum guidelines intended to reduce the risk of injuries due to falls from equipment; it should be emphasized that more conservative measures (e.g., using a lower peak g criterion or greater depth of loose surfacing materials) are always better.

Maximum fall height. Surfacing in the fall zone (see Section 5.3.2.2) of playground equipment should provide protection for falls from the highest accessible part of the equipment. Only surfacing materials that have been demonstrated to meet the 200 peak g criterion at a drop height equivalent to the highest accessible part of the equipment should be used (using the ASTM draft standard for impact attenuation of surface systems under and around playground equipment). Tentatively, until attenuation performance data based on the ASTM draft standard for playground surface systems become available, data from the Mahajan and Beine study (NBS, 1979a) (see Section 5.1.3.5) and manufacturer-supplied results of impact attenuation tests conducted by independent labs can provide some guidance in choosing a suitable surface.

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 accessible 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-high 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 as the highest accessible part. For older and younger children, the maximum heights for upper body devices, as prescribed in this report, correspond to 6.7 feet and 4.7 feet, respectively (see Section 5.7.3.4). On merry-go-rounds the highest accessible part corresponds to the height above ground of handrails near the perimeter of the equipment. For seesaws, the maximum attainable height of the seat positions should be taken as the highest accessible part; the maximum recommended height is 5 feet (see Section 5.7.5.3.2). The highest accessible part of spring rocking equipment corresponds to its maximum height above ground, to account for children climbing on parts higher than the seat assemblies of this equipment.

In addition, it is recommended that the highest accessible part of equipment, as defined above, should normally not exceed 10 feet above the underlying surface for school-age children or 7 feet above the underlying surface for preschool-age children. Given the uncertainties associated with the peak g criterion, and the lack of data on the ability of surfacing materials to protect against severe injuries to the limbs and neck, these maximum fall heights seem reasonable as a general rule. Additional height is not necessary for the play or developmental value of equipment. Given the minimum heights recommended for guardrails and protective barriers (38 inches for school-age children; 29 inches for preschool-age children), the maximum fall heights recommended would effectively limit the maximum height of elevated surfaces to 82 inches for older children and 55 inches for younger children. These heights for elevated surfaces roughly correspond to the vertical grip reach of the maximum user for each age group (78.2 inches for a 95th percentile 12-year-old; 53.9 inches for a 95th percentile 5-year-old). The maximum fall height allowed for preschool-age children needs to be more conservative than that for school-age children, because younger children are at greater risk for falls since their balance and coordination skills are less developed. 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.

The most conservative method for determining the maximum fall height from equipment would be to add the maximum user's height to that of the highest accessible part of the equipment. This method would take into account the fall scenario in which a child standing on the highest accessible part of the equipment, falls and rotates 180 degrees to impact the underlying surface head first. However, adding the stature (63 inches) of the maximum user among older children, a 95th percentile 12-year-old, to the minimum height of a guardrail or protective barrier (38 inches) leaves only a 19-inch allowance for the elevation of the platform, to satisfy the 10-foot maximum fall height for school-age children. This limitation on the maximum height of platforms with guardrails or protective barriers would detract from the play and developmental value of the equipment, and would effectively rule out upper body devices which must be high enough to accommodate the vertical grip reach of the maximum user. Data are lacking on the typical scenarios of falls from guardrails and protective barriers; however, since guardrails and protective barriers do not provide good standing surfaces, it seems more likely that children fall while sitting or climbing on these structures rather than while standing upright on them.

Labeling and instructions. The current CPSC recommendation that all installation instructions, equipment catalogs, and other promotional material should warn against the use of paved surfaces under playground equipment is warranted. There is some consensus in the literature that installation instructions provided by manufacturers of equipment should contain more detailed information about surfacing materials, including impact attenuation test results, maintenance requirements, advantages and disadvantages of different surfacing materials, and recommendations for acceptable surfacing materials and their depths (Butwinick, 1980; Davis, 1980; Frost, 1980; Canadian draft standards, CAN/CSA-Z614, 1988; German standards, DIN 7926, Part 1, 1985).

Installation instructions that accompany each piece of equipment should provide some guidance for choosing a protective surfacing treatment that is appropriate for the maximum fall height of the specific piece of equipment and for the environmental conditions that it will be subject to. Therefore, installation instructions provided by the manufacturer should specify the need for protective surfacing and the maximum fall height for which protection is required; in addition, information on environmental conditions and other factors that affect the impact-absorbing potential of materials, such as depth, size and shape of loose material particles, ease of water drainage, and maintenance requirements, should be provided. When attenuation performance data based on the ASTM draft standard for playground surface systems become available, a table showing the maximum fall heights at which commonly used materials have satisfied the 200 peak g criterion should be distributed with each piece of equipment; this table should specify the depth of materials and any other critical properties of the materials tested, such as the size and shape of loose particles. Manufacturers of surfacing materials should supply the results 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 their products, as stated above.

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. As discussed above, the maximum fall height is taken as the highest accessible part of the equipment. The use of a permanently affixed label is warranted, given that installation instructions are often discarded or lost due to changes in inspection or maintenance personnel.

5.1.4 OTHER CHARACTERISTICS OF SURFACING MATERIALS

As pointed out in Volume 1 and Volume 2 of the current guidelines, consideration must be given to the influence of environmental factors on the performance of surfacing materials. Depending on the environmental conditions of a given location, one surfacing material may be more suitable than another, even though both may satisfy the 200 peak g criterion. Other factors that should be considered include allowance for water drainage, installation and maintenance requirements, flammability, susceptibility to vandalism, ease of cleaning, cost, slip-resistance, and estimated life of the surfacing material.

A number of sources, including Volume 2 of the current guidelines, provided comprehensive summaries of the fall absorbing characteristics, advantages, and disadvantages of different surfacing materials (Beckwith, 1988; King and Ball, 1989; Moore et al, 1987; Canadian draft standards, CAN/CSA-Z614, 1988). Since there is strong consensus among these and other sources (e.g., Aronson, 1988; Esbensen, 1987; Frost and Henniger, 1979; Geiger, 1988; New Zealand standards, NZS 5828: Part 1, 1986) on the relative advantages and disadvantages of different types of surfacing materials, and on the optimal size and shape of loose materials, this information is summarized in Tables 5.1 - 1, 5.1 - 2, and 5.1 - 3.

Recommendations:

Selection of an appropriate surfacing material for the fall zone of a given piece of equipment depends not only on satisfying the 200 peak g criterion for falls from the maximum fall height, but also on evaluating the suitability of the material for the environmental conditions of the playground. The following factors should be considered when choosing a surfacing material: allowance for drainage, durability and impact performance under extremes of temperature and wet conditions, susceptibility to vandalism, ease of repair, estimated life of the material, and installation and maintenance requirements.

Several general recommendations can be made regarding installation requirements for all loose surfacing materials (both organic and inorganic). First, loose materials should not be installed over existing hard surfaces (e.g., asphalt, concrete, rock). Second, because the fall-absorbing potential of loose materials is reduced when they absorb moisture, it is essential to provide for good drainage. Drainage systems are particularly important underneath loose materials in heavily used impact zones such as those under swings and slide chute exits, because extra displacement and compaction of materials in these areas tend to make them the lowest points of the playground. Finally, a method of containment such as a retaining barrier or excavated pit is needed to help keep material in place. Design considerations for retainer walls are discussed in conjunction with trip hazards (see Section 5.2.7).

All loose surfacing materials require periodic renewal or replacement and continuous maintenance, such as leveling, grading, sifting, and raking. These maintenance requirements are necessary to ensure an adequate depth and to remove foreign materials, including sharp objects, which reduce the cushioning potential of loose materials and can cause cut and puncture injuries.

Because unitary synthetic materials vary considerably in composition and design and in their suitability for different play settings and climatic conditions, generalizations about their installation and maintenance requirements cannot be made.