ORIGINAL ARTICLE

Comparative performance of playground surfacing materials including conditions of extreme non-compliance

A H Gunatilaka, S Sherker, J Ozanne-Smith

Injury Prevention 2004;**10**:174–179. doi: 10.1136/ip.2003.004010

See end of article for authors' affiliations

Correspondence to: Dr Ajith H Gunatilaka, Monash University Accident Research Centre, Building 70, Clayton Campus, Monash University, VIC 3800, Australia; ajith.gunatilaka@general.monash.edu.au

Objective: A recent case series study found that only 4.7% of 402 playgrounds in which arm fractures occurred in Victorian schools complied with the recommended 20 cm depth of tanbark. Tanbark depths at fall sites varied between 0–27 cm and the mean was 11.1 (5.0) cm. The purposes of the present study were to (1) measure impact attenuation properties of shallow and compacted depths of tanbark; (2) validate laboratory measurements with in situ data; (3) compare impact attenuation properties of compacted tanbark with an Australian manufactured rubber based surface material; and (4) study the impact performance of rubber and tanbark hybrid surfacing.

Methods: A standard test headform was dropped on tanbark and rubber surfaces in a laboratory setting to measure peak impact deceleration and head injury criterion (HIC) values. Variations in surface depth ranged from 2 cm–20 cm (tanbark) and 2 cm–9 cm (rubber). Drop height ranged from 0.5 m–2.5 m.

Results: Peak deceleration and HIC increased with increasing drop height and decreasing surface depth. Laboratory measurements at depths less than 8 cm overestimated peak deceleration and HIC values compared with in situ playground measurements. Impact attenuation of a 9 cm thick bilaminate rubber material was comparable to that of an 18 cm depth of compacted tanbark. Rubber-tanbark hybrid surfaces showed improved impact attenuation over individual surfaces.

Conclusions: Compacted tanbark of depth less than 8 cm is ineffective in attenuating playground falls, resulting in excessive impact deceleration and HIC values. Shallow and compacted tanbark found in many Victorian school playgrounds poses a high risk for severe head injury. This calls for stricter enforcement of playground surface depth compliance.

Playground related injuries are a significant public health issue resulting in traumatic experiences for children and substantial medical costs for the community. They represent approximately 6% of all hospital treated childhood injuries in Victoria, Australia.[1] Intracranial injuries, which comprise 10%–34% of playground injuries, represent most of the now rare fatal playground injuries.[1–4] Upper limb injuries due to falls comprise 43%–59% of playground related injuries.[1 3 4]

Height of equipment from which children fall and the playground surfacing onto which they land are two important risk factors for playground related injury.[5 6] Current playground standards in Australia and New Zealand recommend a peak deceleration value less than or equal to 200G and a maximum head injury criterion (HIC) value less than or equal to 1000 to prevent severe head injury,[7] although their effectiveness in preventing arm fracture is unknown. These measures have been interpreted to represent a maximum equipment height of 2.5 m and an impact absorbing loose fill material minimum depth of 20 cm.[7]

A recent playground injury study conducted in Victorian primary school playgrounds found that over 85% of playgrounds complied with the recommended maximum equipment height, peak deceleration, and HIC.[8] Out of the 402 fall related arm fractures investigated, 389 (96.8%) falls occurred on tanbark, a surface material recommended by playground safety standards. However, only 19 (4.7%) playgrounds complied with the recommended surface depth of 20 cm. In the fall zones where children landed tanbark surface depth ranged from 0 to 27.1 cm and the mean surface depth was 11.1 (5.0) cm.

A Canadian case-control study also found that while over 80% of falls investigated were onto an impact absorbing surface, the median surface depth was 3 cm, well below the recommended safety standard.[6] This prevalence of non-compliant depths of tanbark in playgrounds warrants systematic investigation of impact attenuation properties of such surfaces. Furthermore, greater understanding is required of how over 85% of playgrounds tested by Sherker *et al* complied with the recommended peak G and HIC values while only 4.7% complied with the depth recommendation.

Several previous studies of laboratory based impact attenuation of playground surfaces have been reported in the literature. Ramsey and Preston investigated a variety of playground surfacing materials including 15.2 cm (6 inch), 22.9 cm (9 inch), and 30.5 cm (12 inch) depths of wood mulch, wood chip, sand, and gravel, and manufactured mats, asphalt, and concrete to determine their shock absorbing properties.[9] Lewis *et al* extended this work by comparing impact attenuation of sand, gravel, wood chips, grass sod, and synthetic rubber matting under various environmental conditions.[10] To compare the impact attenuation properties they dropped a tri-axial accelerometer onto a 15.2 cm (6 inch) thick layer of each material from a drop height of 152.4 cm (5 ft). Materials were tested under dry, wet, and frozen conditions. Murgatroyd and Bullen reported the impact absorbance of several playground surface materials of depths between 10 cm and 30 cm.[11] Bullen and Jambunathan reported the safe fall heights for several playground surfaces of 10 cm to 30 cm depth under dry loose, dry compacted, and wet compacted conditions.[12] Mack *et al* studied five types of loose fill playground surfaces at a variety of drop heights and material depths, and found that impact attenuation improved as surface depth was increased. They concluded that rubber was superior to wood chips, sand, and pea gravel.[13] These studies have not investigated impact performance of surface conditions observed in situ—that is, very shallow and compacted tanbark.

Because over 95% of Victorian school playgrounds investigated had tanbark depths less than 20 cm at the fall sites, including many with less than 10 cm,[8] it is useful to know the impact attenuation properties of such shallow surface depths. Although peak deceleration and HIC values were measured in the study reported by Sherker *et al*, these measures were taken only at drop heights and surface depths as dictated by specific cases of simulated playground falls. Therefore, systematic impact attenuation properties of tanbark of varying depths for falls from specific heights were not provided. We conducted laboratory tests to systematically investigate how peak deceleration and HIC vary as surface depth is varied from 20 cm to 2 cm. We also compared the impact attenuation properties of an Australian made rubber based product with those of tanbark and a hybrid surface comprising a rubber based mat and tanbark.

OBJECTIVES

The objectives of this study were to answer the following research questions: (1) What is the effect of non-compliant surface depths of tanbark and drop height on impact deceleration and HIC measurements? (2) How well do laboratory based tests of playground surfacing compare to in situ results? (3) What is the comparative performance of rubber based playground surface materials in terms of impact attenuation? (4) What is the comparative impact performance of hybrid surfaces comprising rubber and tanbark?

METHOD

The tanbark used for this study was purchased from a routine commercial lot that was made by passing Radiata pinewood through a chipper and a hammer mill and selecting wood chips that passed through a 14 mm sieve but not through a 7 mm sieve. Peak deceleration and HIC values corresponding to falls from drop heights of 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m onto tanbark were measured in a laboratory setting using a standard drop test headform. Tanbark was installed in a wooden box with internal dimensions of 1.25 m×1.25 m as specified in the Australian playground standard.[7] The wooden box was placed on a level, hard concrete floor.

First, tanbark was loosely filled to a depth of 20 cm to simulate conditions in a playground right after installing tanbark to the recommended minimum depth. After measuring peak deceleration and HIC at this depth, tanbark was compacted by stamping on it by foot by an adult until it could not be compacted further in this manner. Compaction was done to simulate the conditions encountered in many school playgrounds that are heavily used by children. Once compacted, the original 20 cm tanbark depth reduced to 18 cm. Peak deceleration and HIC measurements were repeated under these conditions. Then a quantity of tanbark was removed to simulate loss of tanbark due to wind, displacement, etc, and the surface was compacted and levelled to give a 15 cm depth and measurements repeated. This procedure was then repeated to obtain peak deceleration and HIC for compacted tanbark depths 12, 8, 6, 4, and 2 cm.

Five rubber based manufactured playground surface mats that were tested are described in table1. Each mat had a cross sectional area of 1 m×1 m. Mat1 comprised a single layer of fused fine rubber granules. The other four mats were bilaminate surfaces comprising a top layer of fine rubber granules and a bottom layer of large shredded rubber particles (fig 1). One additional test was conducted with a 2 cm thick layer of compacted tanbark placed over the 2 cm thick single layer rubber sample.

The drop test headform used for these experiments (Playground Clearing House, Phoenixville, PA, USA) comprises a metal sphere of 15.5 cm diameter and a weight of 5.4 kg (fig 2). An accelerometer is located in the centre of the sphere. The accelerometer is electrically connected to a handheld computer using a cable. The handheld computer, which is triggered by the headform's impact, computes the peak deceleration (G), impact duration (ms), Gadd severity index, and HIC. The validity of this headform has been previously verified.[14]

Figure 1 Cross section of rubber based impact absorbing bilaminate material 4 with 6.0 cm base and 1.5 cm top layer.

Table 1 Description of rubber based surface materials used

Material	Description
Mat1	2.0 cm single layer
Mat2	2.0 cm base, 1.5 cm top
Mat3	3.5 cm base, 1.5 cm top
Mat4	6.0 cm base, 1.5 cm top
Mat5	7.5 cm base, 1.5 cm top

Figure 2 The drop test headform used for peak deceleration and HIC measurements.

A metal tripod with a pulley at the top was used to raise the headform to a specified height for each drop test. Drop height was measured from the top of the tanbark surface to the bottom of the headform. The headform was allowed to stabilize at the raised height and a quick release mechanism was activated to initiate a drop. At least three drop tests were done at each drop height and tanbark depth, and the highest readings of peak deceleration and HIC are presented following the procedure recommended by the standard.[7]

To assess the validity of laboratory based results by comparing them to in situ measurement, results corresponding to falls from heights in the four ranges 0.99–1.01 m, 1.49–1.51 m, 1.99–2.01 m, and 2.49–2.51 m were extracted from in situ measurement data gathered by Sherker *et al* using the same headform.

Some laboratory based tanbark studies reported in the literature have been done under precisely controlled temperature and humidity conditions. The measurements reported in this study were conducted in a laboratory with large open doors and, hence, temperature and humidity were uncontrolled ambient values similar to in situ playground conditions.

RESULTS

Peak deceleration and HIC values obtained by varying drop height from 0.5 m to 2.5 m were directly related to drop height and inversely related to tanbark depth (fig 3). At the maximum fall height of 2.5 m, 8 cm of tanbark depth produced peak deceleration nearing 200G and HIC nearing 1000.

Laboratory measured peak deceleration (fig 4) and HIC (fig 5) data were in good agreement with in situ data for tanbark depths of 8 cm or greater. However, laboratory measurements deviated sharply from in situ measurements for tanbark depths less than 8 cm.

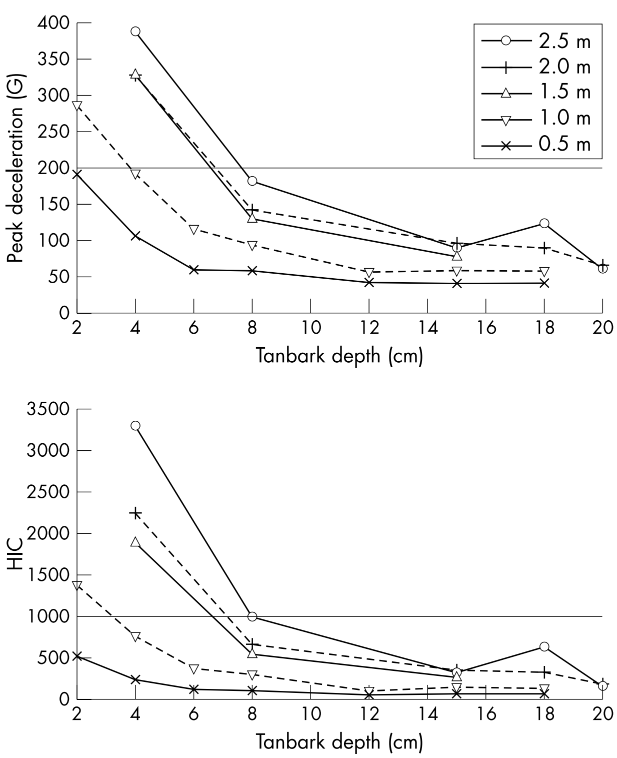

Figure 3 Peak deceleration and HIC obtained in laboratory testing of tanbark at different drop heights and tanbark depths. Horizontal lines indicate the minimum performance standards.

Peak deceleration and HIC for rubber based playground surface mats described in table1 were obtained by varying the drop height from 0.5 m to 2.5 m (fig 6). Peak deceleration and HIC measurements increased with drop height and they were inversely related to mat thickness (fig 6). Impact attenuation properties of a 2 cm single layer rubber based surface material (Mat1) appear to be close to those of a 2 cm layer of compacted tanbark (fig 6). Impact attenuation properties of 9 cm bilaminate (Mat5) are nearly identical to those of an 18 cm deep compacted tanbark layer. A compacted tanbark layer of 8 cm depth has impact attenuation capabilities that lie between those of a 5 cm bilaminate (Mat3) rubber surface and a 7.5 cm bilaminate (Mat4) rubber surface (fig 6). Only Mat4 and Mat5 performed within guidelines recommended to minimize risk of head injury. The thinnest (2.0 cm) rubber mat exceeded maximum recommended peak G and HIC at drop heights as low as 1.0 m.

The hybrid combination comprising a 2 cm thick single layer rubber material (Mat1) and 2 cm deep compacted tanbark showed impact attenuation performance similar to that of a 3.5 cm bilaminate rubber surface (fig 7). While a 2 cm deep compacted tanbark layer and a 2 cm thick single layer rubber material individually resulted in peak deceleration close to 300G at a drop height of 1 m, exceeding recommendations, the hybrid surface outperformed either single material on its own with peak deceleration less than 150G.

DISCUSSION

A 20 cm depth of loosely filled tanbark has excellent impact absorbing properties (fig 3). The 20 cm deep loose filled tanbark did not even register an impact on the test device when dropped from heights of 1 m and below. Compacted tanbark of 8 cm or more also has acceptable impact attenuation as indicated by peak deceleration and HIC values within limits recommended to minimize risk of head injury. Peak deceleration and HIC values appear to rise sharply as depth decreases, exceeding 200G and 1000 HIC when tanbark depth is below 8 cm.

At 0.5 m drop height, all surfaces tested safely attenuated headform impact. Peak deceleration and HIC increased in direct relation to increase in drop height. At 2.5 m drop height, HIC exceeded critical guidelines when surface depth was 8 cm or less.

Data show good agreement between in situ and laboratory based data when tanbark depth is 8 cm or more (figs 4 and 5). However, laboratory measurements sharply exceed in situ measurements for shallower depths. We hypothesize that at shallow tanbark depths the headform may interact with the wooden bottom of the container leading to overestimated values of peak deceleration and HIC in laboratory tests. Nevertheless, this highlights the fact that when tanbark depth is below about 8 cm, the tanbark is incapable of attenuating the impact and hence, such shallow tanbark depths in playgrounds should be avoided to prevent serious injuries.

The large variability of in situ peak deceleration (fig 4) and HIC measurements (fig 5) at depths below 8 cm probably indicates the wide variation of hardness in the substrates underneath the playground surfaces where in situ measurements were conducted. We hypothesize that these variations in substrates are sufficiently masked by tanbark when the depth is greater than 8 cm as indicated by the limited scatter of in situ peak G and HIC data corresponding to such depths. We emphasize that this result should not be interpreted as a justification for maintaining a tanbark depth less than 20 cm. Under extreme non-compliance of tanbark depth, dangerously high peak deceleration and HIC values may result if the surface substrate is hard and compacted.

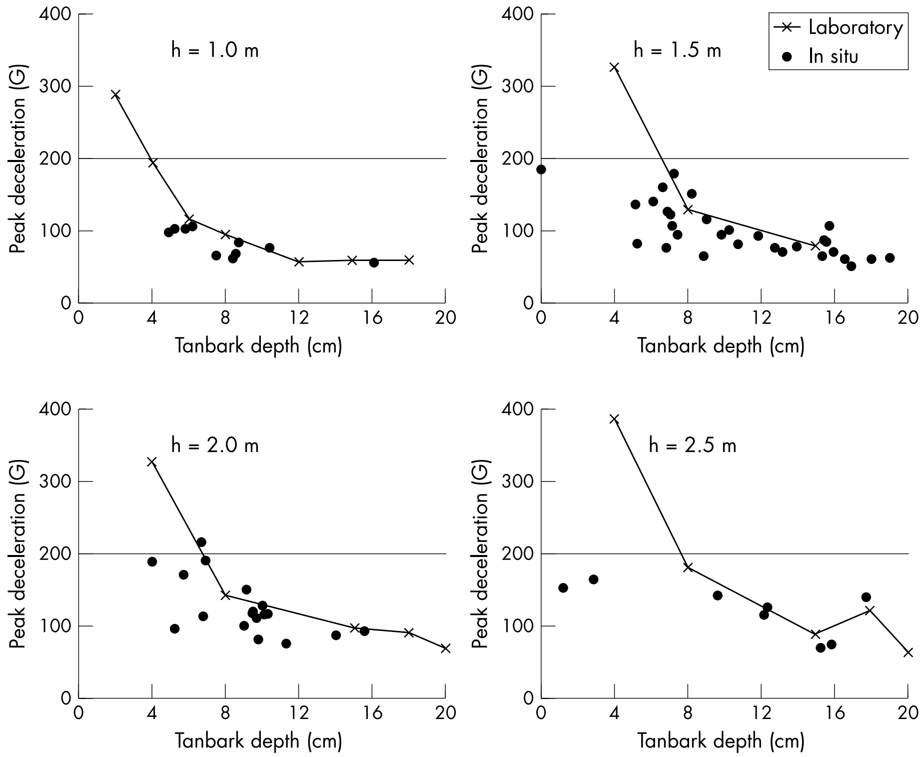

Figure 4 Comparison of in situ and laboratory based peak deceleration values for four different drop heights at various tanbark depths. Horizontal lines indicate the minimum performance standards.

Although thick rubber based materials have good impact attenuation properties, the initial cost of installing such material is much higher than that for tanbark. Therefore, these materials may not be affordable for many playground owners. A number of playgrounds have adopted a hybrid approach in which rubber based surfacing is used for high traffic areas such as slide landings and under swings where tanbark compaction and displacement are excessive while tanbark is installed in surrounding areas. However, as tanbark around rubber surface is displaced or compacted, the boundary between the rubber material and tanbark has potential to become a tripping hazard. It may be preferable to have the rubber surface completely submerged in tanbark to avoid tripping hazards. Although it does not prevent the displacement of tanbark, the rubber based surface would, at least, provide a guaranteed minimum level of protection if tanbark gets displaced due to usage. Although the use of a thin rubber mat underneath tanbark may be better than

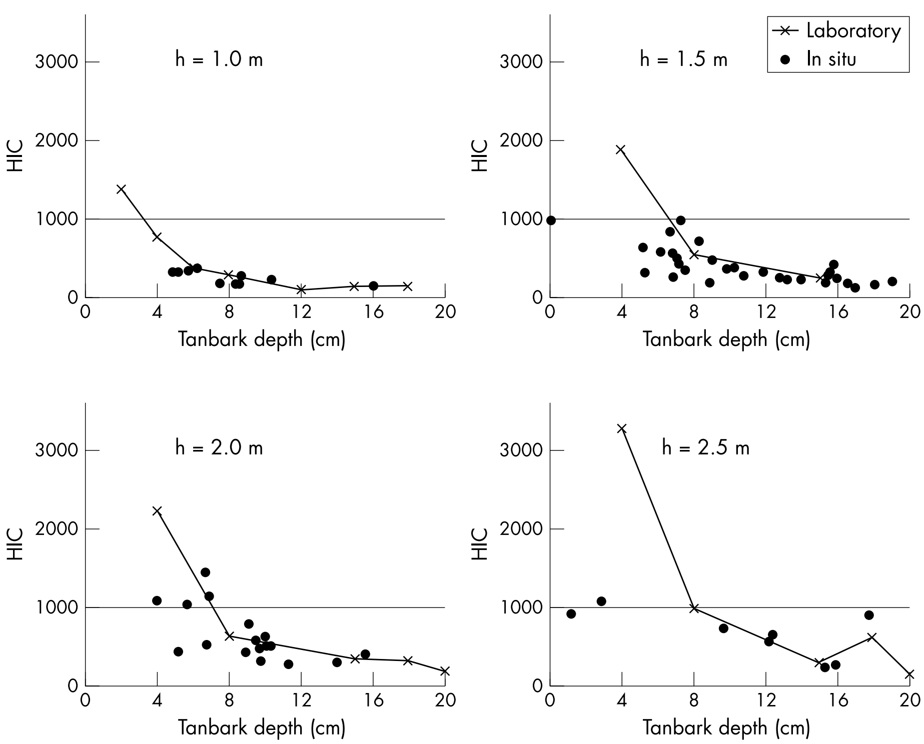

Figure 5 Comparison of in situ and laboratory based HIC values for four different drop heights at various tanbark depths. Horizontal lines indicate the minimum performance standards.

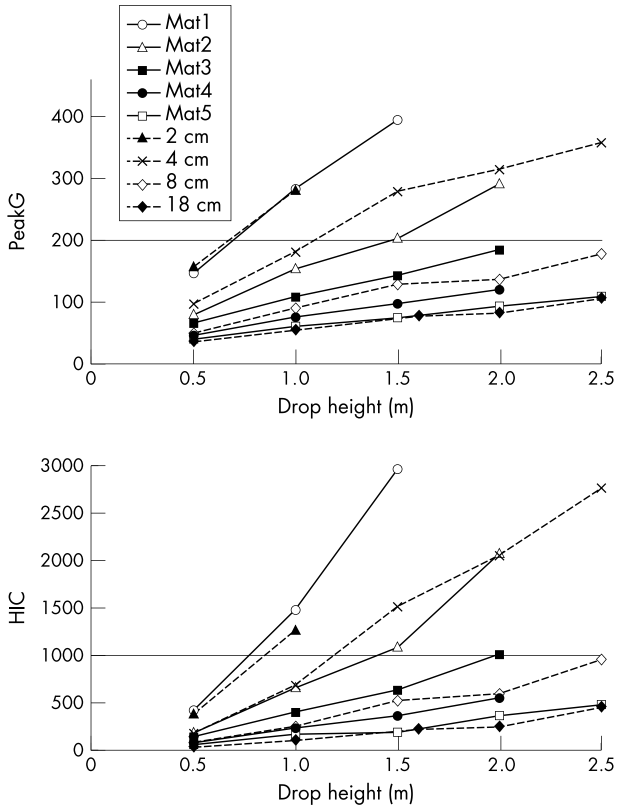

Figure 6 Comparison of peak deceleration and HIC values of five synthetic impact absorbing mats and compacted tanbark layers of four different depths. Horizontal lines indicate the minimum performance standards.

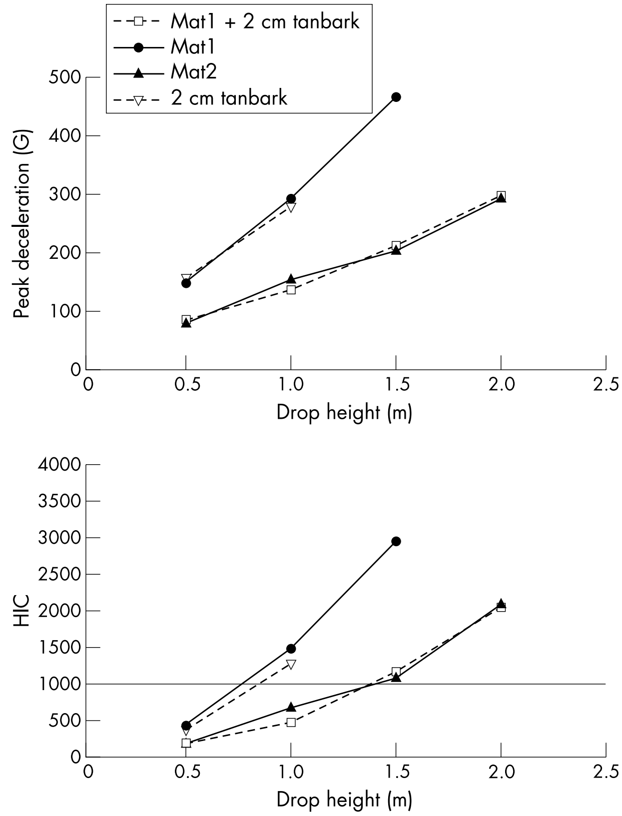

Figure 7 Comparison of impact attenuation properties of synthetic and tanbark combination with synthetic material alone and tanbark alone. Horizontal lines indicate the minimum performance standards.

installing tanbark directly on hard ground, there is no substitute for proper maintenance of the surface material.

The findings of this study are limited by the fact that they are based on laboratory measurements rather than in situ data. However, one objective of the study was to compare laboratory based and in situ impact attenuation, and the difference in these two types of measurements has been discussed here. Another limitation lies in the use of laboratory compaction as a proxy for real life compacting in playgrounds. Rapid laboratory compaction of tanbark may not accurately represent gradual compaction and organic decomposition that takes place in real playground surfaces. A third limitation is the fact that only a single sample of loose fill surface material was used for the study. Repeating the measurements with additional types of material such as sand and pea gravel to inform the safe design of various playgrounds around the world would have been useful.

Some of the strengths of this research are that (1) it is the first study to compare in situ and laboratory based testing of playground surfaces; (2) it is the first study to systematically compare Australian manufactured rubber based playground surfaces to tanbark, and to investigate rubber-tanbark hybrid surfaces; and (3) this research has for the first time identified the critical surface depth at which the substrate beneath the surface is no longer isolated from an impacting body.

CONCLUSIONS

In a laboratory setting, compacted tanbark with a depth of 8 cm or more produces peak deceleration and HIC values that comply with the values recommended in the playground safety standard. Shallower tanbark produces peak deceleration exceeding 200G and HIC exceeding 1000. Peak deceleration and HIC at a specific surface depth are directly related to drop height. While all tested surface depths are capable of safely attenuating a drop from a 0.5 m height, HIC exceeds critical guidelines at a drop height of 2.5 m if surface depth is less than 8 cm.

For tanbark depths of 8 cm and greater, laboratory measurements agree well with in situ measurements for similar drop heights. Laboratory measurements at shallower depths overestimate peak deceleration and HIC values compared with previously reported in situ playground measurements.

Rubber based bilaminate playground surfacing material of 7.5 cm and 9.0 cm thickness have better impact attenuation properties than an 8 cm thick compacted tanbark layer. In fact, 9.0 cm thick bilaminate playground surfacing material has impact attenuation properties nearly identical to an 18 cm deep layer of compacted tanbark. A hybrid combination, where tanbark is laid on top of a rubber based surface material, may be a useful compromise that provides a guaranteed minimum level of safety.

IMPLICATIONS

Laboratory tests and in situ measurements show that impact deceleration and HIC values may exceed recommended guidelines if tanbark depth falls below 8 cm. Because impact deceleration and HIC will be strongly influenced by the hardness of substrate at shallow surface depths, we recommend that substrate guidelines also be included in playground safety standards.

While it is strongly advisable to comply with the 20 cm depth recommended by safety standards, extreme noncompliance of tanbark depths below 8 cm should be avoided by all means to minimise the risk of serious head injury. The

Key points

- A recent study found that a large proportion of Victorian school playgrounds had shallow tanbark depths that did not comply with the recommended depth of 20 cm.
- The aim of the present study was to compare the impact attenuation performance of shallow compacted tanbark surfaces, rubber based play surfaces, and a hybrid combination of these two materials, and to compare laboratory results to in situ performance.
- Impact performance of compacted tanbark of depth greater than 8 cm measured in a laboratory setting agreed well with in situ data and complied with the maximum recommended peak deceleration of 200G and HIC of 1000 respectively.
- Results indicate that tanbark depths less than 8 cm may present unacceptable risk of serious head injuries by failing to protect the child from impacting the substrate beneath the surface.
- This finding calls for stricter enforcement of tanbark maintenance guidelines.

implications on other injuries such as arm fracture are not clear as a relationship between peak deceleration and arm fracture has not yet been established. Only after injury specific criteria are determined, should any reduction in minimum performance surface depth be considered.

ACKNOWLEDGEMENTS
This study was funded by a grant from the National Health and Medical Research Council. An award from the Monash University Accident Research Centre Strategic Development Program (AG) and a Monash University Postgraduate Publications Award (SS) assisted with the preparation of this paper. The authors are thankful to Associate Professor James Nixon of the University of Queensland Department of Paediatrics and Child Health for the generous loan of the headform device.

Authors' affiliations
A H Gunatilaka, S Sherker, J Ozanne-Smith, Accident Research Centre, Monash University, Melbourne, Australia

REFERENCES
1 **Altman A**, Ashby K, Stathakis V. Childhood injuries from playground equipment. *Hazard* 1996(29):1–13.
2 **Ball DJ**, King KL. Playground injuries: a scientific appraisal of popular concerns. *J R Soc Health* 1991;**111**:134–7.
3 **Health Canada**. *CHIRPP injury reports: injuries associated with playground equipment.* Available at: http://www.hc-sc.gc.ca/pphb-dgspsp/injury-bles/chirpp/injrep-rapbles/plygrnd_e.html.
4 **Tinsworth D**, McDonald J. *Special study: injuries and deaths associated with children's playground equipment.* Washington, DC: US Consumer Product Safety Commission, 2001.
5 **Charlmers DJ**, Marshall SW, Langley JD, *et al.* Height and surfacing as risk factors for injury in falls from playground equipment: a case-control study. *Inj Prev* 1996;**2**:98–104.
6 **Macarthur C**, Hu X, Wesson DE, *et al.* Risk factors for severe injuries associated with falls from playground equipment. *Accid Anal Prev* 2000;**32**:377–82.
7 **Standards Australia/New Zealand**. *AS/NZS 4422 Playground surfacing-specifications, requirements, and test methods.* Homebush, NSW, Australia/Wellington, NZ: Standards Australia/New Zealand, 1996.
8 **Sherker S**, Ozanne-Smith J. Are current playground safety standards adequate for preventing arm fractures? *Proceedings of 1st Asia-Pacific Injury Prevention Conference & 6th National Conference on Injury Prevention and Control.* Perth, Australia, 2003.
9 **Ramsey LF**, Preston JD. *Impact attenuation performance of playground surfacing materials.* Washington, DC: US Consumer Product Safety Commission, 1990.
10 **Lewis LM**, Naunheim R, Standeven J, *et al.* Quantitation of impact attenuation of different playground surfaces under various environmental conditions using a tri-axial accelerometer. *J Trauma* 1993;**35**:932–5.
11 **Murgatroyd JA**, Bullen F. Shock absorbing surfaces for children's playgrounds. *Proceedings of International Research Conference on the Biomechanics of Impacts.* France: Bron, 1990:257–68.
12 **Bullen F**, Jambunathan J. *The design and selection of undersurfacing systems for children's recreational areas.* Australian Civil Engineering Transactions, The Institution of Engineers, Australia, December 1991, vol CE33, No 4: 263–8.
13 **Mack MG**, Sacks J, Thompson D. Testing the impact attenuation of loose-fill playground surfaces. *Inj Prev* 2000;**6**:141–4.
14 **Sherker S**, Ozanne-Smith J, Rechnitzer G, *et al.* Development of a multidisciplinary method to determine risk factors for arm fracture in falls from playground equipment. *Inj Prev* 2003;**9**:279–83.