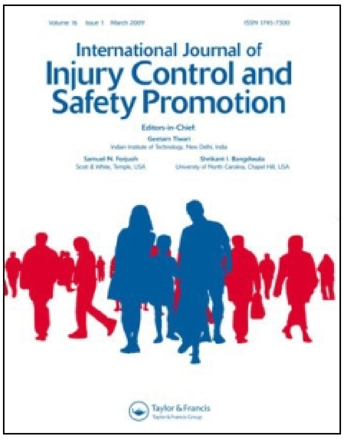

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The efficacy of safety barriers for children: absolute efficacy, time to cross and action modes in children between 19 and 75 months

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The efficacy of safety barriers for children: absolute efficacy, time to cross and action modes in children between 19 and 75 months

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We examined the efficacy of safety barriers by testing their capabilities to prevent or delay crossing. Children between 19 and 75 months tried to climb different barriers selected for their age group, which represented the most common types of panel and horizontal bars barriers available on the market. Success or failure in crossing, time to cross and crossing techniques were analysed. Barrier characteristics' influenced its restraining efficacy. Children's success rate varied between 10% and 95.3%. None of the barriers assured a considerable protective delay. Three major action modes were identified: head over waist (HOW), head and waist (HAW) and head under waist (HUW). Generally, children adopted the safer action mode, HOW, to cross most barriers. Younger children often adopted unstable action mode in barriers with crossable gaps. Although some standards might need to be re-evaluated, there are no childproof barriers. Barriers are time-delaying devices that cannot substitute supervision and education.

Keywords: child safety; climbing; motor skills; protective devices; design

1. Introduction

Falling from heights and drowning are two leading causes of death in children.

Drowning is the second leading cause of unintentional death in the EU (MacKay & Vincenten, 2007) and worldwide (Peden et al., 2008). Most victims are boys (Blum & Shield, 2000; Brenner, 2003; Peden et al., 2008; Peden & McGee, 2003; Vincenten, 2004) and the most vulnerable are children under 5 years of age (Peden et al., 2008; Peden & McGee, 2003; Vincenten, 2004). The drowning rate in low-income and middle-income countries (LMIC) is six times higher than in high-income countries. In LMIC, most drowning deaths occur during daily activities in natural bodies of water and water collecting systems such as buckets, wells and cisterns. By contrast, in high-income countries (HIC) most childhood drowning occurs in recreational settings (Peden et al., 2008). Between 1 and 4 years of age, children in HIC are most likely to drown in swimming pools (Brenner, 2003; Quan, Gore, Wentz, Allen, & Novack, 1989). For that reason, the development of early swimming competence (Brenner, Saluja, & Smith, 2003) and the access to swimming pools have been widely discussed (Blum & Shield, 2000; Brenner, 2003; Scott, 2003).

Falls also represent an important cause of injury and death. They are the leading cause of non-fatal child injury (Peden et al., 2008) but the distribution of fatal falls worldwide is not homogeneous. The rate of fatal falls is around six times higher in LMIC than in HIC, probably because there is an easier access to unprotected staircases, roofs and unprotected rooftops in low development countries. These factors may create particular injury risks for falls (Peden et al., 2008).

Falls from heights (e.g., windows, balconies or stairs) are a major problem particularly in urban areas, with multiple-storey buildings. Different studies report that these falls are more frequent in boys, younger than 5-years old (Bulut, Koksal, Korkmaz, Turan, & Ozguc, 2006; Istre et al., 2003; Mayer, Meuli, Lips, & Frey, 2006; Peden et al., 2008; Vish, Powell, Wiltsek, & Sheehan, 2005), and tend to peak around summer months (AAP, 2001; Lallier, Bouchard, St-Vil, Dupont, & Tucci, 1999; Mayer et al., 2006; Pressley & Barlow, 2005; Vish et al., 2005).

Preventive strategies to reduce the incidence of drowning and falls from heights include environmental modifications, such as the installation of guards and barriers (on balconies, stairs, windows, terraces,

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galleries, swimming pools). These barriers are also used to prevent or delay children's access to dangerous places. Regulations and standards for safety barriers vary in different countries around the world; some are voluntary, others are mandatory (MacKay & Vincenten, 2007; Neto et al., 2008). Discrepancies in regulations and technical variability of solutions are a relevant component of this problem. Studies indicate that many times drowning and falls occur due to inadequate physical constraints, like inappropriately fenced swimming pools (Blum & Shield, 2000; Brenner, 2003), balconies with rails too spaced apart, or window sills too low (Istre et al., 2003). A correct installation and maintenance of safety barriers is also fundamental. When parents and caregivers perceive a safety deficit, they frequently try to compensate it by adopting inappropriate measures such as covering barriers with inefficient malleable and poorly fixed nets, or placing solid protections that reduce rescue success in case of fire. Those are unsafe solutions that may cause dangerous situations not only for children but also for the whole family, could be avoided through the implementation of an adequate building code (Neto et al., 2008).

Decisions about height and other characteristics of barriers have been based upon morphological descriptions of potential users, usually of a static nature. However, the perception of a complex built environment must be described as a dynamic process of movement as people discover architectural shapes and layouts as they move (Hölscher, Meilinger, Vrachliotis, Brösamle, & Knauff, 2006). Children, particularly, move in very creative ways and develop motor solutions for successfully crossing such devices. Gibson (1979) used the term affordance to describe the possibilities for action provided for the actor by the environment. To perceive an affordance, in Gibson's view, is to perceive how one can act when confronted with a particular set of environmental conditions. Children are continuously exploring their environment, and as new motor solutions become available new affordances become potentially detected. Therefore a barrier designed for restraining a child might be perceived as a great challenge to climb, and an effective barrier may easily become useless if a child discovers an alternative solution.

Research is required into children's ability to climb different types of restraining devices to argue for appropriate requirements in standards. To our knowledge, only four studies have focused on children's ability to climb safety barriers (Jaartsveld, Wolde, & van Aken, 1995; Nixon, Pearn, & Petrie, 1979; Rabinovich, Lerner, & Huey, 1994; Riley, Roys, & Cayless, 1998). The results of these studies indicate that the effective protection of the barriers is often very low, especially for older children, but it is more visible in higher barriers. Other design characteristics such as the flexibility of the barrier, the existence of support points to climb, or the existence of a retrofitted profile also seem to significantly influence the success rates in some barriers (Jaartsveld et al., 1995; Rabinovich et al., 1994). A very important finding is that when barriers do not offer total security, children who succeed in crossing do not need much time to do it. The mean time to overcome barriers was less than 30 s in most situations tested by different studies (Jaartsveld et al., 1995; Rabinovich et al., 1994; Riley et al., 1998).

In this study, we attempted to determine the efficacy of different types of restraining devices that represent market available solutions by testing their capabilities to prevent or delay crossing by children between 19 and 75 months.

2. Method

2.1. Participants

We used a convenience sample of children from 19 to 75 months ($N = 88$), divided by two age groups: group A (30 children, 20 boys and 10 girls, from 19 to 35 months; $M = 28.02$, SD $= 4.33$ months); and group B (58 children, 28 boys and 30 girls, from 36 to 75 months; $M = 59.94$, SD $= 9.29$ months). The children had no behavioural disorders, motor problems or uncorrected sensorial deficits that would impair the performance of the task. Subjects belonged to two institutions and were engaged in regular Physical Education programs.

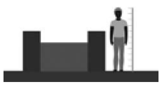
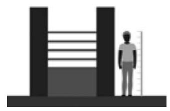
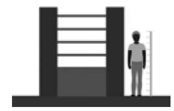
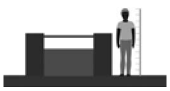
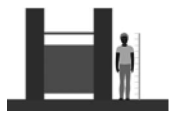
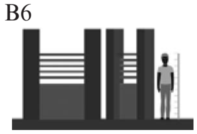
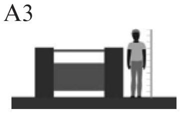
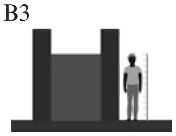
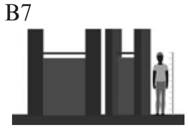
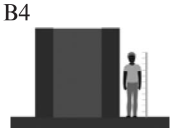
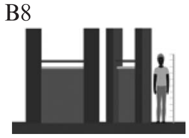
2.2. Task

Wearing comfortable clothes, children were asked to climb different types of barriers selected for their age group in a random sequence.

The experimental procedure is explained thoroughly in the ANEC technical report (Neto et al., 2008). A total of three barriers for group A and eight barriers for group B were tested, following recommendations and standards for panel and horizontal bars barriers (Table 1).

Instructions and encouragement were provided by a member of the experimental team or by the day care teacher. All children were filmed in their day care centre, with their teachers/educators nearby, in order to reduce the impact of a non-familiar environment. In group A, several attractive toys were placed on the opposite side of the barrier in order to catch children's attention. Limit time to pass a barrier was 300 s. Children who couldn't cross the barrier after 300 s were allowed to go to the other side and play with the toys for a brief period in order to keep them motivated for the next barrier. For safety purposes, a gym mat was placed on the other side of the barriers and

Table 1. Description of the barriers selected for the different age groups.

Age group		Age group			
Children between 19 and 35-months old		Children between 36 and 75-months old			
Drawing	Short description	Drawing	Short description	Drawing	Short description
A1 	H = 50 cm	B1 	H = 110 cm 50 cm + 4 gaps of 11 cm + 4 bars of 4 cm	B5 	H = 138 cm 50 cm + 4 gaps of 18 cm + 4 bars of 4 cm
A2 	H = 67 cm 45 cm + 18 cm gap + 4 cm bar	B2 	H = 113 cm 11 cm gap + 80 cm + 18 cm gap + 4 cm bar	B6 	H = 110 cm 60 cm + 4 bars + backing rod (8.5 cm inwards; gap of 10.4 cm)
A3 	H = 78 cm 11 cm gap + 45 cm + 18 cm gap + 4 cm bar	B3 	H = 110 cm	B7 	H = 110 cm 100 cm + backing rod (8.5 cm inwards; gap of 10.7 cm)
		B4 	H = 150 cm	B8 	H = 110 cm 100 cm + 2 backing rods (8.5 cm and 6.5 cm inwards; gaps of 8.5 cm and 9.19 cm)

Reference child, 1.10 m tall; H, Total height of the barrier.

members of the experimental team stood nearby the child to provide protection if necessary.

In group A, all the 30 children tried to climb the three barriers. However, in group B, due to the greater number of barriers tested, the experimental situation was filmed on different days. As some children missed school in one of the testing days or presented some kind of restriction, the sample for each barrier was variable (between 38 and 52). All trials were videotaped, from behind, at a 25 Hz frequency. The video recordings were subsequently pasted into movie fragments for analysis. The following items were then considered: (1) success/failure in crossing the barrier, (2) time to cross the barrier (from the moment of the first contact with the barrier, before the climbing action, until contact with the floor on the other side, or until the last visible frame when contact was occluded by the barrier) and (3) passing technique (action modes adopted for crossing).

The influence of different barrier characteristics in time to cross was analysed through the comparison of pairs of barriers that share common characteristics (structure or height) differing in particular aspects (e.g., height, existence of footholds, retrofitted profile).

The action modes for crossing were classified following the criteria of action control and safety (Figure 1). To determine which passing technique was adopted in each situation, two coders analysed the movie fragments. Inter-observer reliability was 0.95.

It was considered that when crossing a barrier with maximum control, children kept their vertical posture, with the head over the waist (HOW). Arms can move easily and balance is not greatly affected. The risk of falling is minimal. The second action mode is generally used when the level of difficulty of the barrier restrains the amount of options. In these situations, vertical balance is sacrificed in favour of a position that offers a greater contact between the body and the barrier. The barrier is crossed with the head and waist (HAW) at the same level. This technique is more dangerous and guarantees less balance than the previous one. The third action mode is the most dangerous one as it is characterised by crossing with the head under the waist (HUW). This might represent a situation of a highly probable fall.

Sometimes the child exhibited more than one action mode to cross a barrier (e.g., started with HOW but when the second leg crossed the barrier shifted to a HAW mode). This and other possible mixed action types were registered and classified as 'mixed techniques'.

Informed consent was obtained from the children's parents. Caretakers and institutions were fully informed about the nature and purpose of the study. Approval from the Ethics Committee of the Faculty of Human Kinetics (Technical University of Lisbon, Portugal) was obtained.

2.3. Statistical methods

For the statistical analysis frequency distributions, measures of central tendency and chi-square test (χ^2) were adopted. To analyse the time delaying capabilities of different barriers, comparisons were made using the paired samples test or the Wilcoxon signed ranks test in the cases in which the normality assumption was violated.

3. Results

3.1. Crossing different barriers: children's success rate

The most obvious way to assess the efficacy of a barrier is to determine the percentage of effective crossings when trying to climb it. The children's success rate is the inverse of the safety rate for a given barrier.

Results show that as ages increased, children became more skilful in this sort of tasks. In the younger group, the most difficult barrier could prevent crossing in 90% of the cases; in the less complex barrier 70% of all children exhibited one of the above mentioned crossing techniques. In the older group the more complex barrier allowed crossing for one third of the sample; however, the less complex barrier presented a success percentage of 95.3%, that is, almost everyone could pass it (Figure 2).

To better understand the relationship between age and ability to cross barriers, we divided group B in 2 age groups: from 36- to 59-months olds, and from 60- to 75-months olds (Figure 3).

Group B results' indicate that none of the barriers seemed to be efficient enough to avoid most children

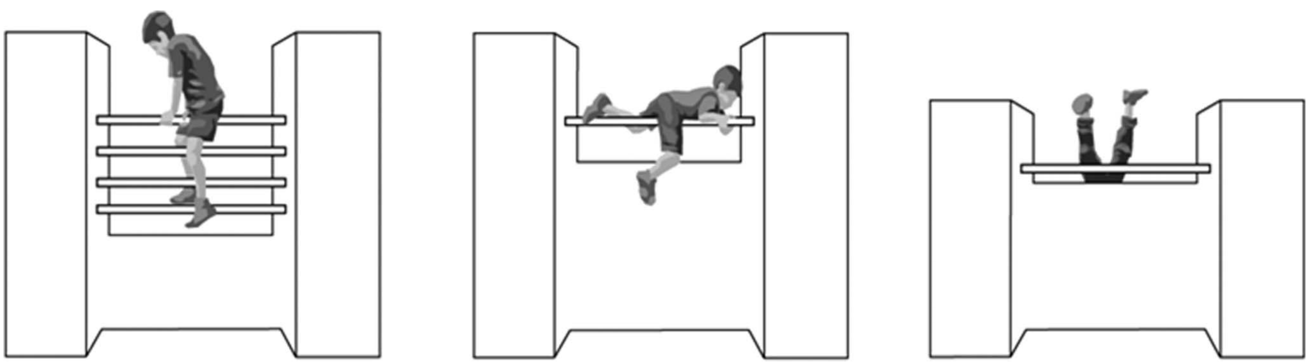


Figure 1. Examples of three different action modes. Left – HOW (head over waist); Centre – HAW (head and waist); Right – HUW (head under waist).

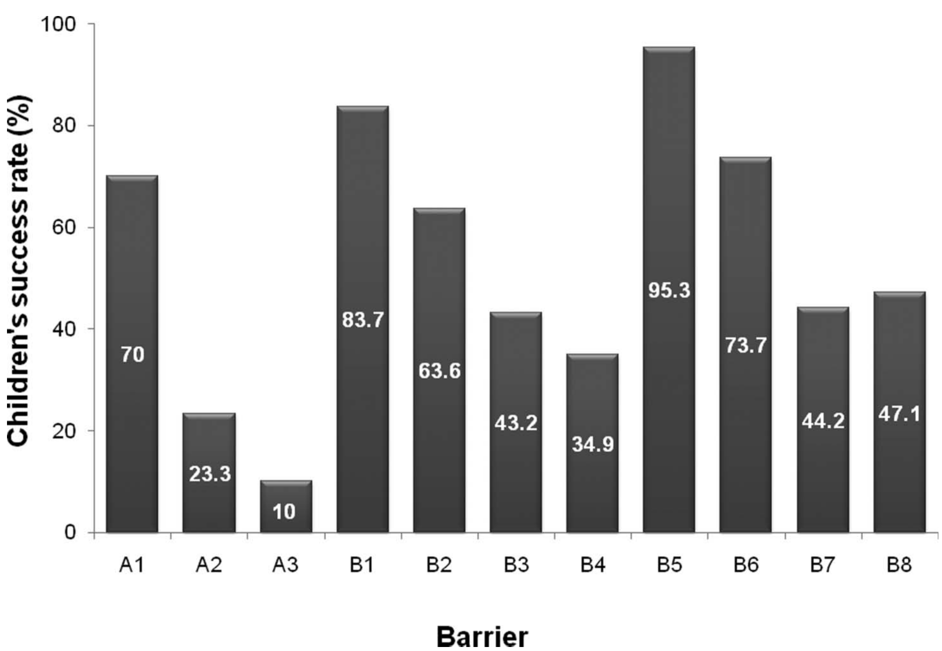


Figure 2. Percentage of success in crossing different barriers.

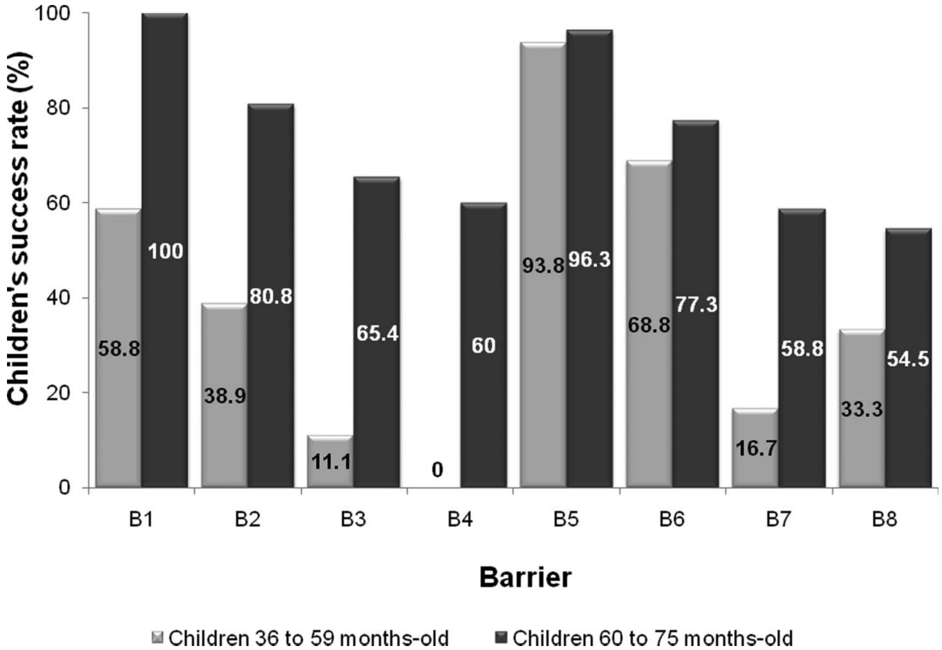


Figure 3. Success rate in crossing different barriers by children 36- to 59-months old and by children 60- to 75-months old.

over 60 months crossing it. The most difficult barrier was B4. This barrier seems to prevent crossing of the youngest children since no child under 60 months could cross it.

There were no differences in gender success rates found in our study except for barrier B7 ($\chi^2(1) = 6.32$, $p = 0.025$) that was crossed mainly by boys.

3.2. *Crossing different barriers: measuring the time to cross*

From a child safety point of view it is important to investigate the delaying capacity, expressed by the time needed to cross each barrier. To meet this purpose, we analysed the time the best climbers took to cross different barriers.

Each barrier was crossed by a different number of children (from 15 to 41 in group B). The most difficult barriers were crossed only by the most skilful climbers but the easiest barriers were crossed by good and bad climbers. To reduce the influence of different skill levels, and since in terms of safety we should consider the fastest children, we selected the 15 best climbers in each barrier to analyse the time it took to cross. This analysis was limited to group B since in group A the number of children that crossed some barriers was too reduced for testing. The results are shown in Table 2.

The average time to cross for the best climbers varied between 6.6 s (B1) and 14.33 s (B4). Results indicated that mean time to cross was always lower than 15 s, and only three barriers (B2, B4 & B6) were able to offer a crossing time greater than 10 s. The most demanding barrier for the best climbers group (B4) was crossed in a maximum time of 36 s.

Table 2. Best climbers' time to cross for different barriers in Group B.

	Time to cross of the 15 best climbers (in seconds)			
Barrier	Mean	SD	Min	Max
B1	6.60	1.30	4	9
B2	10.93	3.39	5	17
B3	9.13	3.94	3	14
B4	14.33	7.39	6	36
B5	7.60	1.84	4	10
B6	10.80	4.28	4	18
B7	6.87	2.95	3	12
B8	8.80	3.59	2	12

The analysis of all the episodes of successful crossing indicated that 231 (94.3%) occurred in less than 30 s, 13 (5.3%) took less than 60 s and only 1 (0.4%) episode lasted longer than 1 min. These values clearly reflect the idea that there are no absolute safe barriers.

There were no significant differences in gender for time to cross most barriers. Only barriers A1 ($Z = -2.05$, $p = 0.041$) and B8 ($Z = -2.17$, $p = 0.030$) were more rapidly crossed by boys.

3.3. *Selected comparisons between barriers*

In order to determine the influence of different barrier characteristics in children's success rate and time to cross, seven pairs of barriers were compared (Table 3).

Table 3. Influence of different barrier characteristics in children's success and time to cross.

Barriers compared			% of success in crossing			Time to cross (s) Mean			
1^{st} B	2^{nd} B	Characteristic compared	1^{st} B	2^{nd} B	χ^2	1^{st} B	2^{nd} B	Z	T
B3	B4	Height	43.2	34.9	31.99***	10.60	14.33	−2.35*	
B1	B3	Footholds	83.7	43.2	6.62**	8.42	11.74	−2.12*	
B1	B6	Inwards rod (with footholds)	83.7	73.7	4.31*	10.77	15.45	−2.99**	
B3	B7	Inwards rod (no footholds)	43.2	44.2	19.67***	10.47	9.33	−1.16	
B3	B8	2 Inwards rods (no footholds)	43.2	47.2	24.57***	11.19	13.56	−.483	
B7	B8	Extra inwards rod (no footholds)	44.2	47.2	29.86***	9.70	12.20		−2.56*
B6	B7	Footholds (with inwards rod)	73.7	44.2	9.12**	11.71	11.93		−.093

*$p < .05$.
**$p < .01$.
***$p < .001$.

We selected barriers that had similar general characteristics but differed in one specific characteristic, such as height (measured from the floor to the top of the barrier), the existence of footholds (defined as elements outlined for the hand/ toe grip that provide support for the foot used for climbing a barrier) or the existence of a retrofitted profile (created by one or two backing rods on the upper part of the barrier). The comparisons between pairs of barriers indicated that some characteristics of the barriers influence children's success rate and time to cross.

The results indicated that increased height reduced the percentage of success in crossing ($\chi^2(1) = 31.99$, $p \leq 0.001$) and delayed time to cross ($Z = -2.35$, $p = 0.019$). On the other hand, footholds can transform a safer barrier into a dangerous one. Barriers with horizontal bars, which provided footholds, were easier to cross ($\chi^2(1) = 6.62$, $p = 0.010$) and took less time to be crossed than panel barriers of the same height ($Z = -2.12$, $p = 0.034$). Footholds also make retrofitted barriers easier to climb ($\chi^2(1) = 9.12$, $p = 0.003$).

In barriers with footholds, the existence of a cylinder rod rotating inwards reduced the crossing probability ($\chi^2(1) = 4.31$, $p = 0.038$) and delayed it ($Z = -2.12$, $p = 0.034$). However, in solid panel barriers it facilitated climbing ($\chi^2(1) = 19.67$, $p \leq 0.001$), as it offered additional grasping support. The percentage of success was even higher for barriers with two cylinder rotating rods in a different plane ($\chi^2(1) = 24.57$, $p \leq 0.001$), probably for the same reason. Two inward rods instead of one, increased children's success rate ($\chi^2(1) = 29.86$, $p \leq 0.001$) but significantly delayed time to cross ($t(19) = - 2.56$, $p = 0.019$).

3.4. *Action modes used to cross different barriers*

Most children crossed the barriers with their HOW (i.e., action mode HOW) (see Figure 4). This seems to be the preferred mode when the barrier characteristics and the child's skill level allowed this kind of crossing. However, barriers with crossable gaps (e.g., barrier A2 and A3) seem to promote different kinds of crossing, because it is easier to pass between the gap with the HAW at the same level or with the HUW. These movements are dangerous crossing techniques because they limit the control of balance and movement, and may be associated with undesirable falls. The gaps of 18 cm were wide enough for younger children to pass without squeezing. Children in our study did not attempt to pass through the 11 cm gaps. The action mode HOW is much more frequent in the older group, indicating enhanced motor control and skill. Children in the younger group might still be testing other ways to cross barriers, even though they may look like unsafe behaviours.

4. Discussion

The findings of this study support previous investigations in children's ability to climb barriers (Jaartsveld et al., 1995; Nixon et al., 1979; Rabinovich et al., 1994; Riley et al., 1998) as they pointed to an easy and fast crossing of common barriers that are usually adopted as architectural solutions for restraining devices. The results also evidenced differences among various types of barriers.

As age increases, children become more skilful in climbing barriers and by the age of 5 most children seem to be able to climb any kind of the most common barriers available on the market. The most efficient barrier in our study was the 1.50-m solid panel. This barrier was crossed by 34.9% of the children in group B and represents the most demanding standard worldwide for swimming pools protection.

A greater height and the non-existence of footholds enhanced barriers restraining capacity. The influence of retrofitted profiles seems to be dependent on other barrier characteristics. In this study, retrofitted profiles

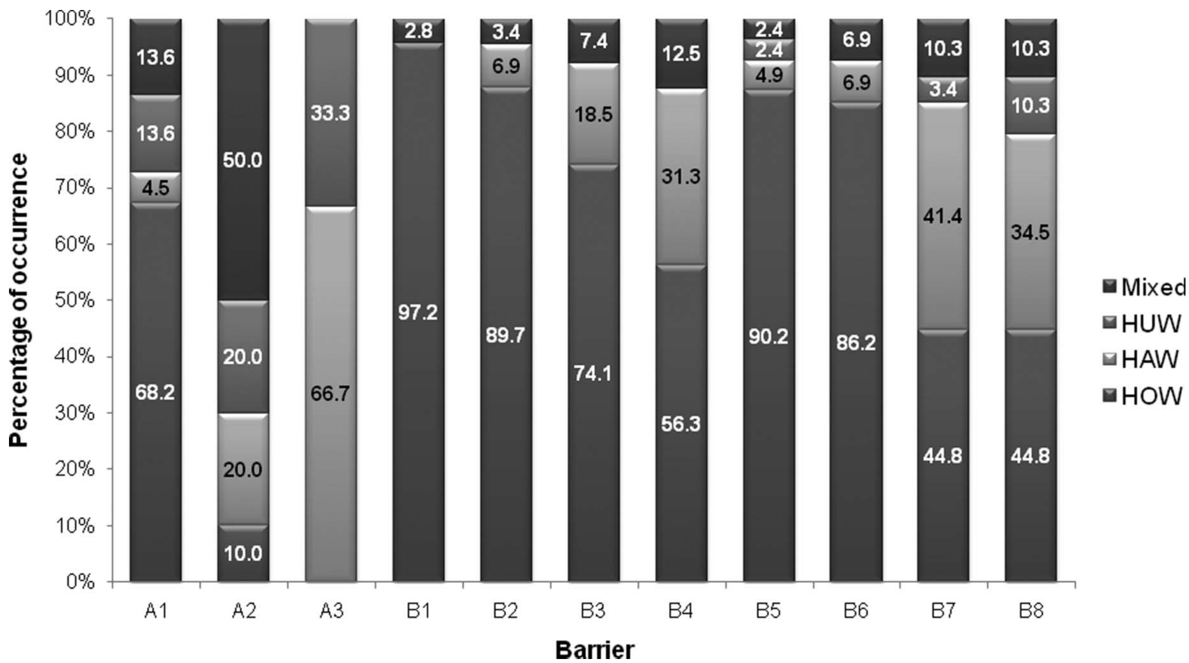


Figure 4. Percentage of occurrence of the action modes used to cross different barriers.

increased the restraining capacity of barriers with footholds but decreased it in solid panel barriers, probably because they offer extra grasping points.

Barriers may create temporary negative affordances in the environment. However, when children are able to cross barriers they can do it very rapidly. In this study, 94.3% of all the successful crossings occurred in less than 30 s and only one crossing (0.4%) lasted more than 1 min. These data reinforce the need for an appropriate adult supervision around risky environments. Parents and caregivers must be aware of that, and strategies to control and reinforce supervision must be developed. Lapses in appropriate supervision have been identified as a factor across a range of childhood injuries (Morrongiello, 2005; Saluja et al., 2004).

In most barriers, we found no significant differences between gender for the success rate or time to cross. This indicated that the prevalence of injuries in boys was not related to differences in physical ability but might be related to other factors, such as risk perception, different socialisation of gender roles and propensity for risk-taking behaviours (Hillier & Morrongiello, 1998; Little, 2006; Morrongiello & Dawber, 1998, 1999, 2000, Morrongiello, Midgett, & Stanton, 2000; Morrongiello, Ondejko, & Littlejohn, 2004; Morrongiello & Rennie, 1998; Schwebel & Barton, 2005).

Generally, children adopted the safer action mode (HOW) to cross most barriers. However, younger children tended to adopt more often more unstable solutions mainly in barriers with crossable gaps (e.g., barrier A2 and A3). These barriers are in accordance with some international regulations (e.g., NF P01-012, 1988) that state the dimension of 0.18 m, if the gap is $\geq$ 0.45 m above the floor. Many balconies have protections that follow this standard but our results recommend its re-examination. In this study, there were no occurrences of entrapment of the child in the barrier or of snagging of their clothing on portions of the barriers, probably because children didn't try to pass through the 11-cm gaps. The space between bars is an important issue, which requires further investigation with younger children, because gaps shouldn't allow children to pass through and should not have dimensions that might cause children's entrapment. In some situations the gap is wide enough for the child's chest to pass through but not wide enough for the head, causing strangulation if the child's body slides down and the head is entrapped (i.e., head entrapment by feet-first action). Head entrapment might also occur by head-first, this generally occurs when children place their heads through an opening in one orientation, turn their heads to a different orientation, then are unable to withdraw from the opening.

Some studies indicate that the characteristics of the environment and the perceptions of children's accident risk shape caregivers behaviours (Chen et al., 2007; Gärling & Gärling, 1990; Miller, Shim, & Holden, 1998). Parents' perceptions, attitudes and behaviours towards child safety were investigated by Vincenten, Sector, Rogmans, and Bouter (2005). Most parents indicated that the major difficulty to protect their children from accidental injury is that they are not able to watch their children constantly. Lack of awareness or knowledge about the causes of accidents was the second response. Therefore, permissive standards are major problems since inappropriately designed barriers might not be easily identified by parents and supervisors, who might be misled to trust in a non-existent protection effect. Conversely, when a lack of safety is identified, parents and supervisors must seek advice to install and secure safety barriers properly, in order to avoid the use of unsafe solutions, which maintain or even increase the risk situation, causing a false sense of security.

Parental perceptions about children's injury risk are often unrealistic (Michalsen, 2003; Moran & Stanley, 2006a; Spinks et al., 2008). Moran and Stanley (2006a) showed that parents, especially those whose children were enroled in swimming lessons, had an overly optimistic view of the protective role of swimming ability in toddler drowning prevention. Approximately one-third of swim school parents believed that it was better to develop toddler swimming ability rather than rely on adult supervision. In a second study (Moran & Stanley, 2006b), the authors demonstrated that an education programme, which addressed parental misconceptions, improved parental awareness of toddler water safety.

Pool fencing and window and balcony guards have been referred as effective strategies to reduce drowning and fall injuries and deaths (Vincenten, 2005; Vincenten & Michalsen, 2002). However, parents should not totally rely on barriers to prevent access to dangerous places or falling injuries, since physical barriers are just a part of a trilogy that also involves education and supervision. Education is a valuable component that should be incorporated into most injury prevention strategies. As biological entities, children do not have full awareness of right and wrong, or appropriate/inappropriate. The perception and categorisation of things and behaviours as good and bad requires an adequate and continuous set of demonstrations, instructions and knowledge. That is a part of the educational process, and it cannot be expected to develop spontaneously. Education might also be a useful tool to encourage the use of passive measures, such as applying safety barriers near risk environments. However, there is no evidence to show that education on its own can reduce injuries (Peden et al., 2008). Adequate supervision is the third element. Our data suggests that even a moment can offer the opportunity to cross a barrier. Parents and caregivers must be aware of that, and strategies to control and reinforce supervision must be developed. A barrier may be just a time delaying device that can give the opportunity for adult intervention; not an absolute preventive tool.

It is important to note that in the present research we did not address barriers overcome by children in real-world settings. Strictly for methodological reasons, children were encouraged to pass the barriers under controlled and assisted conditions, and they were asked to do something they know they should not. In fact, that is the only way to test the overcoming resilience of a barrier. The results of the study are a natural outcome of the method developed. The findings reported must take this methodological strategy into consideration.

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