Dimensions and Design of swimming pool fences and balcony and stairs barriers to protect children from falling and from passing trough, bellow or above

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1. PROBLEM

1.1 Background

Climbing is a natural movement. Children often use climbing tasks as a challenge, as it promotes development and skill improvement. They will climb anything that attracts them, making no special distinction for guards or barriers designed to restrict their access to risky environments. These barriers (on balconies, stairs, windows, terraces, galleries, swimming pools) are used to prevent falling from buildings or inside buildings, and to prevent or delay children's access to dangerous places.

There are a variety of regulations and standards for barriers in different countries around the world; some are voluntary, others are mandatory. Yet, discrepancies between standards may introduce additional variability of behaviour and risk perception by parents, institutions, and community. There is no evident scientific support for the standards, but the complete absence of standards or legal recommendations is also unacceptable. Research is required into children's ability to climb different types of restraining devices to argue for appropriate requirements in standards.

Barriers are not a play device, and they must be understood as a limitation (because they constrain behaviour) and as a limit (absolute boundary). Although some morphological or motor skill determinants may contribute to the ability to pass the barriers, the educational role of the family and caregivers is of absolute relevance. In the present research, and strictly for methodological reasons, children were encouraged to pass the barriers. That is the only way to test the overcoming *resilience* of a barrier. The comparisons between barriers, the characteristics of the techniques used by the children, the effects of body dimensions and age, are a natural outcome of the method that we've developed. The findings that we'll report must take the methodological strategy into consideration. In fact, children were asked to do something they know they shouldn't.

1.2 Purpose of the project

The literature research had the objective of gathering information on norms, law, and regulations about fences and barriers enforced in different countries. A preliminary analysis of fences and barriers helped to categorize them following a reasonable classification system. The design of the barriers was analysed from a child safety point of view for the different age groups under consideration. The review of literature also addressed specific concepts that have implications on the issue of child safety.

Subsequent to the literature research we have carried out practical tests with children with the main purposes of: a) finding out different height requirements depending on the age of the child; b) testing some of the most common solutions in what concerns their ability to climb; c) determining which are the main factors associated with the children's ability to pass through, below or above a fence or a barrier. Additional information was provided by selected anthropometric variables.

The ability to pass barriers and fences was assessed by the absolute overcoming resilience and, if possible to overcome, by the time necessary to "conquer" the obstacle.

1.3 Scope

The project focuses on the skills to pass these objects of children aged from 9 to 75 months. The barriers under analysis replicate some of the major types of restraining devices available on the market. For practical reasons a limited number of barriers had to be selected, because the repeated practice of different barriers may introduce learning and adaptation effects. The panels and barriers that were investigated approximately represent the diversity of solutions. It is not possible to represent all available solutions according to fashion, design or other regional specificities.

2. LITERATURE RESEARCH

2.1 Reference values

Safety barriers should be able to prevent falls and to delay children's access to risky environments. To meet this purpose they should be properly designed. Inappropriately designed barriers might not be easily identified by parents or supervisors, who might be mislead to trust in a non existent protection effect of some unsafe barriers, especially when they are new and good-looking. This fact might put children at an even greater risk since their caregivers' supervision might be insufficient. Requirements for different protection devices should be similar, as movement techniques are partially independent of the purpose of the protection. Menezes and Eloy (2007) identified some major problems in barriers construction:

- Insufficient height: in some cases reaching the top of the barrier is an easy task. Children might climb, loose their balance and fall.

- Space between bars: vertical or horizontal bars often have gaps between them that allow children to pass through. In some situations the gap is wide enough for the child's chest to pass trough but not wide enough for the head, this might cause strangulation if the child's body slides down and the head is entrapped (i.e., head entrapment by feet-first action, see Fig. 1). 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.

- Advanced (outwards) guards , outside the building profile: guards can have a space between them and the front wall of the building or the edge of the balcony floor. Children that walk or crawl in a balcony with that type of protection might easily lose support of their feet or hands and a total or partial fall might occur.

- Handholds and footholds: many balconies are designed with gaps in their structure or may have chairs, flowers, plants or other decorative elements in the vicinity, that provide good support if a child wants to climb.

Figure 1 - A gap of 11 cm allows the child's body to pass entrapping the head.

The design of good barriers has probably the same cost as the design of unsafe barriers, but safe barriers will save lives and money spent on fall related injuries. Some aspects of barrier design are discussed next.

Maximum height of a barrier – measured from the floor to the top of the barrier.

The value for the height of the barrier is frequently defined in the interval from 0,90 m to 1,10 m. Despite these values there are some cases were we can see extreme values as 0,70 m (French Standard for non housing barriers with top $\geq$ 0,60 m) and 1,40 m (Italian Standard).

The French standard (NF P 01-012), for example, makes the distinction between housing building (with the minimum of 0,80 m) and other buildings (defined to 0,7 m). In Portugal, the Portuguese association for child safety (APSI), advises a minimal height of 1,10 m free of support points (e.g., footholds) (Menezes & Eloy, 2007; APSI, 1998).

Maximum Gaps – It is defined by the opening between two elements of a barrier.

This dimension could be defined with the help of a good anthropometric data base, supported by an ergonomic definition of free space. If we guarantee that the smallest children cannot pass trough the gaps we assure that the bigger ones cannot pass either.

The standards for recommended spacing for vertical bars vary according to different recommendations in different countries. Culvenor (2002), analysed data from Australia, New Zealand, the United Kingdom and The United States of America, and found differences in recommendations for balconies between 70 mm and 127 mm, and between 89 mm and 125 mm for playgrounds and pools (see Table 1).

Table 1 - Recommended spacing for vertical bars in barriers from various sources (adapted from Culvenor, 2002, p. 3).

Balconies, etc.	Playgrounds, pools, etc.
127 mm max	125 mm max
125 mm max	100 mm max
100 mm max	89 mm max
90 mm max	
80 mm max	
70 mm max	

The reference values indicated in Table 1 report to 2002. Presently, the most frequent measure found is 0,10 m. However, for children under 3 years-old a standard of maximum 0,09 m would be safer in order to prevent partial falls (Menezes & Eloy, 2007; NP EN 1176-1, 1998; CEN Report, 1999). Exceptions are also found in New Zealand, for example, where 0,13 m for older children is acceptable (New Zealand Building Code).

In CEN TC 252 dealing with child use and care articles 65 mm is always used as a distance that should prevent a child's torso slipping between bars leaving the child's body weight being supported by its neck and thus a strangulation hazard. This 65 mm should also be the maximum distance between the lowest horizontal component and the floor/ground.

Stephenson on his book "The Silent and Inviting Trap" (1988) even states that "All Children under 6 years old, will easily pass trough a gap of 0,15m".

On the other hand, specifications for gaps between horizontal bars are sometimes quite permissive. For example the French NF P 01-012:1998 (adopted by Portugal in 2005 as a voluntary technical specification) states the dimension of 0,18 m, if the gap is ≥ 0,45 m above the floor, being one of the most permissive regulations.

Maximum clearance between the lowest horizontal bar and the floor – It is defined as the maximum gap between the floor and lower part of the barrier.

The main danger in this dimension is to ensure that children do not fall or get their head trapped, causing a trauma situation for children. If the child is sitting and slides with the feet first, there is an actual risk of falling or getting hanged by the head. The dimensions observed varied from 0,03 m to 0,12 m, although for example the Spanish Building code would state for the 0,10 m (UNE 85-237-91). In Portugal, the technical specification LNEC E 470-2005 allows distances of 0,11 m. As previously mentioned, APSI advises for a maximal distance of 0,09 m to avoid situations as seen in Fig. 1 (Menezes & Eloy, 2007). Sometimes the lower part of the barrier is advanced from the front wall of the building. In those situations it is also advisable a maximal distance of 0,09 m to avoid entrapment or even smaller to reduce the risk of falling objects. Many international regulations don’t allow more than 0,05 m in these situations (Menezes & Eloy, 2007).

Footholds, toeholds and handholds – They are defined by the dimensions outlined for the hand/ toe grip and for the foot support used for climbing a barrier.

These elements facilitate the climbing of a barrier. To prevent this, when barriers have decorative elements that provide a good support point if a child wants to climb, they must be covered with a solid panel from the inside with a minimal height of 1,10 m to avoid the support of hands or feet, in order to difficult the transposition. This panel can be transparent for aesthetics purposes (Menezes & Eloy, 2007).

When parents and caregivers perceive a deficit of safety they frequently try to compensate for that situation adopting inappropriate measures such as covering barriers with inefficient malleable nets, which are often poorly fixed; or placing solid protections that difficult rescue in case of fire. This type of solutions, which cause a risk situation not only for children but for the whole family, could be avoided through the implementation of an adequate building code. Options to compensate for incorrect protection devices may be catastrophic, but unfortunately they cannot be avoided. Regrettably, the compliance with the existing building codes doesn’t necessarily state that a barrier meets its safety purposes. Permissive building codes allow for almost every type of barrier, as we can see by the photos presented in Appendix 1.

2.2 Morphological Characterization

2.2.1 Growth from 6 months to 6 years

Human growth evolves in a non linear manner alternating great accelerating growth periods with accentuated proportional disharmony periods, with phases of growth slowness where proportional harmony increases. This temporal growth sequence is fundamental for human organism efficient management of its energetic reserves for growing. Consequently, bigger morphologic growth stability moments (greater proportional harmony) are the most favourable for the occurrence of other learning (e.g. motor abilities, reading, etc.) processes.

The acquisition of motor skills, the development of physical capacities, and the capacity to explore the involving environment is, therefore, a direct consequence of maturity and physical growth.

During first infancy, especially in the first two years, growth speed is very high and morphologic alterations are very fast. Between 3 and 5 years, the growth speed gradually decreases and we can affirm that this period is a developmental phase when children “recover energy” before and after two periods of great growth acceleration, 1st infancy and adolescence.

During the first two years of life weight augmentation is proportionally superior to height increase. This difference is especially critical during the first year when weight increase is approximately 150%-200% and stature increase is only 50% (Tanner, 1962; Sparks, 1992). Stature increases 113% until 5 years (Roche & Malina, 1983). At one year of age, the child total length is 24 cm larger than birth length, and in the second year stature increase is only 9 cm (Jordan, 1988). Despite the growth speed decrease at 5 years, stature increase is still significant, being about 7 cm. From this age until adolescence stature will increase around from 4 to 6 cm each year (Tanner, 1962).

Near-born body proportions reflect intrauterine growth and basically the directions the growth occurred (cranial-caudal versus proximal-distal). Although in the first infancy initial stage there is a predominance of the head comparatively to the trunk and of the trunk relatively to the limbs, the differences between these segments reduce until 3 years of age due to the quick stature growth that occurs during the first two years of life, growth acceleration of the lower limbs.

Initially, the upper limbs are dimensionally superior to the lower limbs. This is a characteristic of first infancy. But from this point on, the tendency is inverted as the lower limbs start growing faster. According to Brandt (1984), since birth until twelve months, the relative proportions of the upper limbs remain rather constant (41%) but the relative proportions of the lower limbs increase from 33,7% to 37% of the child total length, respectively at birth and at the end of the first year.

The enlarged head dimension that is a distinctive characteristic of the children's first year is the consequence of the high girth growth of the head speed during the first months. Throughout the first semester the head girth increases 9 cm, at an average monthly growth speed of 1,5 cm, and during the second semester it only augments 3-4 cm, going from 34-35 cm at birth to 43-44 cm at six months and to 46-47 cm at twelve months (Jordan, 1988; Vaughan et al., 1979).

In near-born and in the first infancy initial phase, despite the predominance of the abdominal region, there is not a clear differentiation between abdomen and thorax. The trunk is cylindrical due to the feeble development of scapular girdle and the great importance of the subcutaneous fat of the hips. The shape of the thorax is also characteristic, being rounded due to the dimensional similarity between the anterior-posterior and transverse diameters and becoming oval when the transverse dimensions begin to grow at a bigger rhythm than other anterior-posterior dimensions. In this phase the difference between biiliocristal or trochanterion and acromiale breadth is still small even if it has bigger increments relatively to thoracic and pelvic breadths.

In the beginning of the second infancy the trunk finally loses its predominance and progressively gains a trapezoidal form due not only to the biacromiale breadth speed growth increase relatively to the trochanterion breadth, but also owing to the accentuated decrease of the abdominal circumference. At the same time, muscular forms become visible.

During the first 5 years of life trunk length increases about 14 cm (Dermirjian, 1980, cited by Roche & Malina, 1983) or 15 cm (Brandt, 1984), representing about 56% of the child's total length at the age of 5 years.

The morphology we have just described for first infancy has repercussions on children's mobility. In these ages the eye-hand coordination and the objects' manipulation is a consequence of the advancement of the upper limbs growth and of the enormous growth speed of the central nervous system. The rounded forms facilitate the child's first body manoeuvres and axial orientation, such as turning and rolling movements, are easy. Creeping, crawling and sitting are easily supported by limbs proportions and by progressive trunk and neck muscles. Walking would be a much more complicated task if the lower limbs were not so short and the transition between sitting and standing would be highly complex (Vieira & Fragoso, 2006).

The low location of the gravity centre is extremely important to the acquisition of multiple motor tasks. While gravity centre at birth is situated approximately 20 cm above the trochanterion, in adult age it is only 10 cm above the same bone. This small difference of 10 cm corresponds to completely different anatomic positions. At birth it is situated at the xiphoid process while at an adult age it is located at the level of the iliac crests or in the 2nd or 3rd sacral vertebra. The high positioning of the gravity centre explains the difficulty that children of these ages have to get completely immobilized after a run (Payne & Isaacs, 1995), and may contribute to the steadiness and balance deficits that can be easily observed.

Another aspect is that, as countries develop in so many different ways, the growing rates in different countries are also very variable. Secular trend, for instance, are perhaps more influential than traditional race differences. Secular trend in China and Southeast Asia as well as in other emergent countries, acts upon children's morphology in a striking way. Normally, secular trend shifts toward a growing dimension, but the trend can also be negative, as demonstrated in countries with serious developmental and economic negative growth.

2.3 Trends in motor development

2.3.1 Acquiring new skills

2.3.1.1 Perceptual development

Babies, infants and toddlers, share a common feature: their perceptual systems are learning to deal with huge amounts of information, bringing pieces and details together, into unified and unique representations of the world. This developmental trend requires sensorial maturation, environmental stimulation, and opportunities to learn. The process of learning how to interact with the environment is a perceptual as well as a motor process. Perceptual development requires maturation support, but cannot be fully explained by maturation. In fact, experience increases acuity of perception, and experience requires action.

Vision plays a major role in this process. As a matter of fact, all senses demand information exchanges with the visual system in order to calibrate all perceptual systems. That happens with auditory, vestibular and tactile information, in a process that origins the perception of a body within an environment, and of a body that moves in that environment. During the first years of life some visual aspects develop very rapidly, such as visual acuity, visual accommodation, peripheral vision, fixation and tracking of objects. For the purpose of this report it may be interesting to focus on depth perception – the ability to judge distances from objects and surfaces (Williams, 1983). It has two basic and distinct forms: the static depth perception that informs about static features of the world, and the dynamic depth perception, that concerns moving objects, moving bodies or both. The visual cliff experiment (Gibson & Walk, 1960) demonstrated that crawling children can visually perceive depth at an edge and behave accordingly. But other studies (Svedja &

Schmidt, 1979; Berthental & Campos, 1990) have shown that there is a clear distinction between locomotor and pre-locomotor children in what concerns the physiological and emotional responses in that experimental condition. The experience of locomotion offers a child a realistic meaning of the situation that was not observed in pre-locomotor children, suggesting that depth perception is a function of experience and not a simple natural consequence of maturation processes.

Visual information, the optical flow to be more precise, dominates the vestibular and the somatosensory information from muscle sensors (that became evident in the "moving room" experiments after Lee and Aronson (1974)). This means that visual information that comes from moving objects, or information produced by moving around or over objects, plays a major role in the organization of posture and the conservation of balance (Thelen, Ulrich, & Jensen, 1989). When passing obstacles or barriers, much of the required coordination is not body-dependent but visually-driven, and that is a problem in early childhood years, when the correspondence between visual flow and other sources of information is not fully established. Once again, the most obvious way to solve this problem is to provide additional experience in these kinds of situations. Keep in mind that barriers may not act as an efficient dissuasion tool; if the child attempts to climb them, the minimization of the risk of falling must also be observed.

In the young infant, some of the most relevant acquisitions are self-perception, the perception of distance and position, the perception of motion and movement, the perception of weight and height.

In the first year, and to be more precise until the onset of walking, the world is perceived as a support surface in which creeping and crawling can take place. In this perceptual world, walls and furniture set the limits for locomotion – they offer the boundaries for a new set of actions, like standing and walking. Vertical boundaries, in particular, are very powerful: they usually do not afford passing over, although they may afford passing under and passing through. Yet, as the perceptual system is rather limited, the correct assessment of body possibilities involves great error margins. Decision making involves a high risk of failure for maturation, perceptual-motor and cognitive reasons.

Accidents are a strange combination of curiosity and mistake: the child's most relevant characteristic is the enormous curiosity about things and finding new possibilities is a never ending story. However, as the sensory and neural systems are not fully mature, a considerable amount of functional error is always present. Estimates of distances and weight are so frequent that collisions and manipulation errors are a natural part of children's daily life. At this moment in life, falling is of limited consequences, because the centre of gravity moves very close to the ground. That will not be the case in older “walking” or “running” children. When falling from upright standing posture, body shape and fat tissues will offer natural protection.

Natural limitations of crawling movement and quadruped posture do not allow a significant climbing experience. Instead, the common use of four limbs in locomotion tasks is a natural limitation to the involvement in risky tasks. Arm strength, and specially a poor strength/weight ratio, act as biological limitations for dangerous climbing experiences.

At the onset of walking everything changes dramatically: a limited support basis and a vertical structured world will replace the former safe *ground world*. Hands can operate with greater autonomy and the perceptual world changes very rapidly – new properties of objects and new spatial relationships feed the brain with a strong, fast and flowing information array.

One of the consequences of this perceptual spurt is that action possibilities suddenly improve but the expected sensory consequences of movement are not tuned with action. During the first year of life a sort of (lovely) characteristic jerk can be observed. In older children that characteristic will not be appreciated, for unexpected consequences of jerky actions can be quite dramatic. The anticipatory control of movement, the additional use of feedback information, and the automatic regulation of movements will progressively reduce jerk. For practical purposes, and as a general principle, don’t forget that movement experience reduces jerk.

2.3.1.2 Rudimentary skills - Transitional skills

It may seem strange, but new walkers have an increased potential for accidents. As we have seen before, they have new capabilities that they don’t master and the anticipation of action outcomes is rather limited. During the second and third years of life the body learns to operate with these new possibilities, developing some rudimentary skills of great importance. The rapid development of higher cognitive processes, associated with increased motor ability, causes rapid (and sudden) changes in this period (Gallahue, 1989).

In the locomotor domain, running and jumping skills are crucial. These movement structures are slowly mastered, but the potential for acting in the world is dramatically altered. Children learn to respond with adaptability and versatility to a variety of external conditions. Combining running and jumping, a common feature in the second and third year of life, allows for the ability to pass vertical walls that were not passable before. Jumping and climbing can be coordinated in complex combinations, and the maximum reachable height “moves” to new standards. Almost everything in domestic areas can be reached and every obstacle may become a challenge. Curiosity has now a new ally: an increased action capacity.

Manipulation, that used to be of a very simple and limited type, is now a powerful resource. Hands can move very rapidly, fingers can operate with dexterity and strength increases. The coordination of both hands can maximize grasping and throwing, and objects can now be operated in very dangerous ways.

Children can now hang on bars, swing and jump, and develop infinite movement combinations. Movements are so rewarding that children repeat them time after time, developing new skills of high complexity. The repetitive nature of movement, and the observation and modelling of peers, combine in such a way that new solutions are continuously discovered. These skills are not a direct and simple consequence of maturation: opportunity for practice, modelling and peer confrontation, and parents encouragement are necessary, in order to achieve highly structured skills and a clear and sharp perception of movement outcomes and consequences.

Many studies have demonstrated that motor performance grows rapidly before 3 years of age. A new consolidation phase can now take place, in which the combination of basic skills in the domains of posture, locomotion and manipulation, transforms the developing organism into a *problem-solving specialist*. By definition, five-year-old children can perform all human basic movements, although performance may change for structural reasons. In fact, significant changes are about to occur in the domains of body growth, mechanic and energetic efficiency and coordination. It is universally recognised that, in movement education, practice makes perfection. Play will develop new symbolic dimensions, peer relations, and sophisticated structures. Most skills will be inserted in play activities, giving origin to more complex games and reinforcing the development of skills. Movement skill that used to be of a functional nature, is now deeply surrounded by pleasure and emotion. Emotional thinking and competition with peers brings new safety challenges.

Contrary to common opinion, play happens in every context and not only in the so-called play spaces. Many activities that show no purposeful behaviour are in fact play activities, as serious as play can be. Unfortunately, parents and caregivers cannot fully address the nature of children's play: play is an attitude, a challenge and a discovery – play can happen everywhere, and it does.

2.3.2 Physical growth and motor performance

2.3.2.1 Climbing skills

Children have an inner urge to climb and improve their motor skills. Little children climb on an object just because they have an intrinsic need to explore their surroundings and develop their motor skills in every possible way. Climbing broadens children's play possibilities. By climbing they can reach new places and see new things, in a challenging way. However, the need for new experiences and the accurate perception of action limits are two separate things. Children still have to learn by experiencing what is possible and what is not, and they inevitably will have accidents as a result of unsuccessful attempts. Reduced strength and strange body proportions do not favour climbing. In the long term they will learn to judge their capacities, they will become more careful and cautious, and little accidents will tend to disappear.

Pivoting may be observed in 3 month-old children (less than 5%) and 50% of all children can pivot before 6 months (Piper & Darrah, 1994). Four point kneeling may be observed at 5 months (10%) and at 7 months 50% of all children can use this locomotion technique. Less than 10% of all children can exhibit a reciprocal creeping technique. These chronological standards indicate that the motor competence for locomotion in small distances may be available before 6 month-old. This information implies that protection for gaps must be attended before the first half of the first year.

From the moment toddlers start to pull themselves up they start practising their climbing skills. Strong and light children are normally better climbers since a basic need for climbing is that the child has the strength to carry his/her own weight. At the age of 6 most children have the skills to climb as an adult. They have similar proportions to an adult, and because they are still small and lightly built they are often better climbers than older people. Until the age of 4 boys and girls do not show significant differences in climbing skills. After this age the boys are developing more strength than girls (van Herrewegen, Molenbroek, & Goossens, 2004).

The ANEC R&T Project (van Herrewegen, Molenbroek, & Goossens, 2004) has identified some influential qualities for climbing: age, height, weight, strength, character, leg length, arm length, grip, grasp, step height, and flexibility. Despite the fact that clothes and shoes do not seem to significantly influence climbing skills in children, they can be the cause of severe accidents. The same report also states that the climbing skill may be influenced by talent (1/3) and by the environment they live in (2/3). It also underlies the fact that good climbers can be recognised when they are still young. They move very easily and relaxed, they can look around and concentrate on a lot of things at the same time while climbing, they take alternating steps, they do not necessarily stay close to the object, they like to climb, and choose automatically the best climbing technique for each object.

The properties of the object also influence its *climbability*. Some influential characteristics are: existence of footholds or handholds, height of the first support point, distances and angles between support points, shape of the support points, roughness of the material, and slope of the surface.

When trying to climb an object, children usually look for a horizontal bar, rail or any other thing they can grab. They pull themselves up with their arms while looking for footholds and support points for their hands. While climbing a wall or a fence they sometimes use their knees and elbows as well. To get on top of an object they throw one leg over the edge of the horizontal support or they push themselves up until they are able to put one foot next to their hands. The first seconds at the *top of the world* may be very dangerous because posture and equilibrium are precarious.

The ANEC R&T Project (van Herrewegen, Molenbroek, & Groosens, 2004) presents a developmental sequence of climbing skills (see Table 2).

Table 2 - Developmental sequence of climbing skills
(adapted from Herrewegen, Molenbroek, & Groossens, 2004, pp 20-21).

Age (years)	Climbing behaviour	Safety concerns
1 - 1,5	Pulling themselves up on rails and edges of furniture, starting to walk, small steps of about 20 cm (stairs and mattress), crawling over small bumps and low obstacles.	They do not see any danger and do not yet know what height means.
1,5 – 2	Walking gets better, climbing on a slide and sliding of, more high steps (foot after foot), stepping over something, trying to keep their balance.	Children do not yet know their own boundaries.
2 – 3	Climbing higher, more balancing.	Children start to know what is possible and what is not and most of all what is allowed. They have little or no fear for heights.
3 – 4	Good balance, jumping of objects, hanging on, sitting on small object.	Children become a bit frightened sometimes: difference between good and bad climbers becomes bigger.
4 – 6	Children are developing all aspects of their motor skills. They can climb the stairs alone. Once they are 6 years old most children can move as adults and they are starting to learn more difficult movements like riding a bicycle with two wheels. Some of these children are able to climb a rope but most can not do this yet. Until this age there is little difference between boys and girls.	Children are a bit frightened but not very scared of heights. Parents will often still come with them when they play outside to keep an eye on them.

Age (years)	Climbing behaviour	Safety concerns
7 – 9	Children like to play fantasy games. They play a lot outside the house without someone watching them. They like to climb on playground equipment and are experts at finding new ways to do this. A lot of them can still not climb a rope. Some of them because they are frightened, some of them because they do not understand the technique of using their legs and some of them because they are too heavy and they are not strong enough to carry their own bodyweight. Their body mass is becoming more important for the ability to climb.	At the age of about 9-10 years children start to understand what height means. From this time on some kids can become more scared of heights than they were before. Especially girls can show some regression in climbing skills at this age.
10 – 14	Children of this age are starting to play more sport games. Puberty will start around the age of 12 and this will change a lot in the lives of the children. Some of them will have to get used to their new body forms and will become averse to physical movement. Differences between boys and girls are becoming bigger. Boys are getting stronger.	As adolescents the children will climb a climbing frame or other objects but they do not play on it, they use it as a place where they can sit and look over the area whilst talking to each other. The chance that they will fall from the object is therefore very small.

A very limited number of studies using acceptable scientific methods and focused on children's climbing ability was identified. Rabinovitch, Lerner and Huey (1994) examined children in the age range of 24 to 54 months in a climbing task with commonly used fences, up to 5 feet height. The results observed in the highest fence (5 ft) showed that the older group (48-54 months) ranged from 8 to 100 percent success rate. Only one fence (ornamental iron fence) offered more than a 90% restriction rate. In this age group, three of the five tested fences were crossed with a success rate of more than 55%. Two fences offered more than 80% success rate. Three-fourths of the children in the youngest groups were able to climb the common chain-link fence at 4 ft.

On the other hand, 4 feet fences seemed very effective in preventing younger children's (24-36 months) climbing behavior. At this age group, 60% of all 4 ft high fences offered total security (no crossings at all). In this study the time to cross the barriers was also analyzed: the 4 ft fences were crossed in less than 76 seconds (in average) by children of all age groups. This means that some fences were effective in preventing crossing, but if the child can cross it then the time they need to do it is very short. In the older group all children that crossed the fences did that in less than 25 seconds. An analysis of the overall time to cross 4-ft barriers, considering all children that could do it, showed that the children who successfully climbed the fences did so quickly, "providing additional reason for concern about the effectiveness of fencing" (p.740). As expected, there were statistically significant differences in the time needed to cross different barriers.

In this study a roller top and an angled plate top barrier were also tested and the results indicated that they significantly reduced crossing success. In the common chain-link fence the roller top design wasn't so effective in the older group tested (42-48 months) since children had a greater success rate with this retrofitted profile than with the wide-angled plate. On the other hand, in the stockade fence the roller top was more effective since no children in the older group could cross it. Time to cross these barriers was not significantly different from time to cross more conventional fences.

Nixon, Pearn and Petrie (1979) tested vertically ribbed barriers, with horizontal rib spacing of at least 0,91 m, ranging from 0.61 to 1,37 m, in a sample of children up to nine years of age. Results showed that 80% of the two-year-olds did not climb the 2-ft fence, but 50% of the 3 year-old children could climb a 3-ft fence, and one fifth of the three-year-olds could climb a 4-ft fence. The effective protection of this kind of barriers, despite their height, is very low.

Another study that analyzed children's ability to climb was focused on stair guards of 0.90 m (Riley, Roys, & Cayless, 1998). Interestingly, the authors presented a flowchart showing the events leading to a child climbing a stair guarding that included, among other variables, the following morphological items: height, leg and arm length, and strength. In the conceptual framework they also included factors affecting the desire to climb, such as personality, maturity, and desire to experiment, as well as restrictions to climb (guardian behavior, permission to climb, belief in ability, etc.). The results indicated that the time children need to cross the guard is very short (mean climbing time was 13,2 seconds, with a range of 3,2 to 40,9 seconds). The authors have identified three climbing strategies and showed that, in a natural-ecological experiment design, younger and smaller children imitated their older and taller mates. Imitation and influence of older mates is a very interesting factor, because in natural conditions in the home environment older brothers and sisters influence the climbing behavior of their younger siblings. Boys and girls behave differently: boys were more oriented to try climbing behavior, and this fact may be the origin of frequently reported gender discrepancies in epidemiologic based reports.

2.3.2.2 The development of strength

Strength is fundamental to motor performance. Many skills, such as climbing, require a minimal level of strength and can be better performed by strong children. Even daily activities become difficult without enough strength (e.g., older adults who have lost much of their strength might have difficulty climbing stairs, being often at a greater risk of falling).

Muscle strength is related to muscle size or muscle mass, in particular to physiological muscle cross-sectional area. However, changes in strength do not always parallel changes in muscle size, since other factors, such as neurological changes over life span, influence muscle strength (De Ste Croix, 2007; Haywood & Getchell, 2001). Many factors seem to interact to produce the expression of strength (see De Ste Croix, 2007 for a review). Body awareness, neurological, hormonal, age and sex associated changes in muscle strength are important during life span. However, while there is vast literature focusing on determinants of strength development, few studies have investigated common age ranges, muscle groups, testing protocols and muscle actions, making comparisons difficult. Despite this lack of consistency, the age-associated development of strength is reasonably evident, irrespective of the muscle group or action under examination.

As children grow older strength increases steadily (Haywood & Getchell, 2001). Boys and girls have similar strength levels until they are about 14 years where it begins to plateau in girls and a spurt is evident in boys. The exact age in which sex differences become apparent appears to be muscle group and muscle action specific. There is also a suggestion that sex differences in upper body strength occur earlier than lower body strength. This has been attributed to the weight-bearing role of the leg muscles. It has also been suggested that boys use the upper body more than girls in their physical activities, such as climbing (De Ste Croix, 2007).

Davies (1990) tried to determine whether gender differences could be explained by lean arm mass and verified that when grip strength was expressed relative to lean forearm mass no gender differences were found. This indicates that strength is greatly related to muscle mass.

2.3.4 Exploring the world

Newborns can only perceive a limited part of the world. The process that broadens the perceptual capacity, based upon a set of biological changes that are essentially driven by maturation, is called perceptual learning. As all learning processes, it involves repetitive exposure to stimulation, and an active organism that operates in an environment.

It is well known that organisms that have the chance to develop in enriched environments develop better and precocious perceptual-motor skills. Therefore, stimulation is essential for a correct development. But research has also demonstrated that passive stimulation is not enough – growing organisms also demand active exploration of the world. Fortunately, children have a natural tendency to explore things, and that is, for sure, the best embedded mechanism to promote perceptual learning.

Gibson and colleagues (1987) have designed a very interesting experiment to elucidate the process of extracting physical properties of ground surfaces in young children. Experiments were conducted with crawling and recently walking infants on a platform with two different surfaces (rigid and safe against a soft and “squishy” surface). The perception of crossing the surface was significantly different from one condition to another, and exploration strategies were different, not only according to the surface’s nature but also according to crawling-walking experience (Gibson & Pick, 2000). The more bizarre the surface, the more the children needed to explore it. In a second experiment, the two surfaces were placed side by side, offering two options to the child. Younger children showed no preference between options, but “walkers” didn’t hesitate – they chose the rigid and safe surface by a large majority. This experiment shows that safer solutions are naturally adopted by older and more skilled children, emphasizing the main role of experience in the adoption of safer behaviours. Parents and caregivers that adopt extra-protective behaviours must be aware that they are also inhibiting the accurate perception of risk.

The role of self-produced movement in guided locomotion was first elucidated by the Held and Hein (1963) experiment. When comparing active versus passive kittens in the avoidance of a cliff, the results were very convincing: active experience is absolutely necessary to detect environmental affordances and to promote safe behaviour. Kittens that were reared in a passive exploration of the visual world didn’t achieve an adequate behaviour in the presence of a dangerous situation. In what concerns the essential features of biological development we must keep in mind that human infants are not structurally different from other mammals.

In early stages of development, well before the tremendous development of symbolic thinking and language, it is by movement that the exploration of things can occur. That line of reasoning has been slowly incorporated into the western educational basis, and transferred into to educational principles. To a lesser extent, families have perceived that exploring is essential, and that exploring involves risk.

It is also important to remark that movement encouragement at early stages of development promotes greater confidence in the activities, even though pure motor performance may not be clearly enhanced.

2.3.5 The world is full of constraints

At every moment, children’s behaviour arises from the interaction between personal characteristics (individual constraints), social and physical characteristics of the environment (environmental constraints), and the action to be performed (task constraints). If any constraints belonging to one of these three categories change, the resulting movement will change (Newell, 1986).

From a child security perspective, the analysis of the different interacting constraints is of fundamental importance. For example: a change in an individual constraint, such as an increase in height might allow the child to reach objects that were previously unreachable; a change in an environmental constraint, such as change from sunny weather to rain, will make the task of walking across a tile floor, previously dry but now wet, more difficult; and a change in a task constraint such as descending a slope with a steeper inclination might make the descent more difficult, probably causing, in some situations, a switch from a walking to a sliding position. Therefore, to provide a safe environment for the children, we need a good knowledge of the interacting constraints for different situations, since an apparent minor change in a given constraint might lead to an increased risky situation for the child.

In order to prevent childhood injuries we should act upon the interacting constraints. Active prevention strategies are intended to modify the child's behaviour in order to reduce injury risk but they might not be too effective at younger ages. On the other hand, passive strategies focus on modifying the environment (e.g., diminishing the space between rails in a barrier, so that children cannot pass through it, or avoid barriers with horizontal bars, in order to make the task more difficult). Passive strategies seem to be more efficient at younger ages. However, environmental modifications might lead sometimes to risk compensation (i.e., increased risk taking in response to environmental modifications that reduce risk). This behaviour has been demonstrated in children (e.g., Morrongiello, Walpole, & Lasenby, 2007) and in parents, who allow children to engage in greater risk taking when wearing safety gear or when environmental modifications reduce risk (Morrongiello & Major, 2002). Thus, to achieve the maximum benefits from environmental strategies there should be also individual strategies for injury prevention. For instance, even if a balcony has a protection barrier parents should teach their kids not to play there by themselves, and should never neglect their level of supervision. As Morrongiello (2005) pointed out not all environments can be modified to reduce risk, and not all behaviours are easily amenable to modification. Hence, both kinds of strategies should be viewed as complementary and equally important to the prevention of childhood injuries.

It is quite clear that a part of the "random" nature of children's accidents is the changing nature of constraints during infancy and childhood and the rate of change over time. There are good reasons to suppose that probability of accidents increases in periods of fast body changes or in early stages of motor acquisitions. It becomes clear that risk behaviour must be individually defined, and it relates to subjects' characteristics as well as environmental specific demands. According to the ecological approach the individual guides his activity by perceiving affordances, so he must be capable of perceiving the relationship between environmental properties and the properties of his own action system.

2.3.6 Perceiving action limits

As we previously mentioned babies have constrained action possibilities. For instance, they are moved by others before they can move by their own means, but they have full access to visual and auditory information. The information that they pick up from their environment supports the extraction of invariants, i.e., the common things that are perceived in the presence of a repeated event. Individual experience, of course, generates the detection of what can be done with an object or within a specific situation (Gibson, 1969).

During development children learn how to cope with the existing affordances, such as the ability of passing over surfaces due to their properties and negotiable paths, as their own body's proportions, strength and capacity for balance are changing (Gibson & Pick, 2000).

In the process of perceiving affordances children often try to gain experience by pushing the limits of their capabilities. Inefficient or dangerous behaviours usually occur when people, especially children are close to their action boundaries (Barreiros & Silva, 1995). When a wall is too high it inhibits jumping; when it is low enough, jumping is promoted; but in the boundary zone there is an increased uncertainty that might lead to unsafe behaviour. The precise delimitation of affordances in this unsafe boundary area requires specific experience on specific environmental constraints. At this point a new paradox emerges: children may experience dangerous behaviour because they have no experience but the acquisition of experience seems to be a dangerous process.

Many studies have shown that falling accidents are more frequent between 2 and 6 years of age, and this roughly corresponds to a period of experimentation and development of the perception of action limits. Balconies, windows, and stairs represent nearly 50 % of fall related injuries, while falling from trees, play equipments and other "educational" structures represent less than 10 % of related episodes (Kim, Wang, Griffith, Summers & Levy, 2000). When the opportunity for perceiving environmental affordances is restricted, and the competence for the detection of action limits is poor, accidents seem to occur mainly in non-play context.

2.3.7 Risk and risk-taking

From a child safety point of view we consider that risk is related to the probability of accident occurrence and to the severity of a possible accident. If the frequency of accidents that occur in a context is much greater than in other contexts, or if the severity of the accidents that might occur is too serious, even if their probability of occurrence is small, we consider it to be a risky context.

In order to evaluate the risk of a given situation we need to know the interacting constraints in that situation. An unfenced swimming pool, for example, constitutes a situation of a greater risk to a toddler than to an adult that knows how to swim and that can avoid risky behaviours close to the water.

We would like to emphasize that *a safe environment is not the same as a risk free environment*. Not only because that's difficult to achieve, but also because we believe there are positive developmental outcomes associated with risk-taking. The overwhelming emphasis on injury prevention in the current literature has neglected this positive aspect of risk-taking. However, exploration, challenges and risk-taking have an important role on children's development since they provide valuable opportunities for learning, problem-solving and developing social competence. As Greenfield (2004) pointed out: "In today's society there appears to be an aversion to risk; yet, without risk-taking we do not reach our potential" (p.1). As a matter of fact, parental and society apprehension concerning child safety is resulting in an increasingly overprotecting style of parenting and aversion to risk, where possible dangers are exaggerated and safety and caution are strongly promoted. This attitude might result in the avoidance of many worthwhile risks that contribute to child development. On the other hand, the removal of all potential hazards may inadvertently lead to inappropriate risk-taking, since children can seek challenging and stimulating experiences to overcome boredom and lack of stimulation (Little, 2006).

During the process of discovering what the world has to offer the infant sometimes engages in risky situations. In terms of child safety it would be important to determine not only how the child perceives the existing affordances in risky environments, but also how the adult evaluates what is a risky environment for that child, since in the early years the environments the child moves in are controlled and managed by adults.

2.3.8 Adults and supervision

Parental supervision has been considered an essential element in children's safety. Lapses in appropriate supervision have been identified as a factor across a range of childhood injuries (Morrongiello, 2005; Saluja, Brenner, Morrongiello, Haynie, Rivera, & Cheng, 2004). Peterson, Ewigman and Kivlahan (1993) stated that there is no substitute in most risky situations for developmentally appropriate parental supervision of young children. However, to define adequate supervision we must consider a variety of constraints, such as the age of the child, the hazards present in the environment and the type of injury to which the child is most susceptible. For example, an adequate supervision of a 5-month-old baby in a swimming pool implies touch and continuous attention, while intermittent attention from a distant location might be adequate supervision for 5-year-old playing in a safe environment.

Caregiver behaviours should also be considered within a larger context, as proposed by Saluja et al. (2004) in their conceptual model for caregiver decisions about injury prevention strategies. According to theses authors, risk perception is dependent on the characteristics of the caregiver, the child, and the environment.

Prevention of childhood injuries has led to a debate concerning the relative merits of focusing on modifying the environment *versus* adaptive behaviour to reduce injury risk. Researchers have tried to devise ways to decrease the necessity for supervision by pursuing different kinds of interventions to reduce environmental hazards (e.g., stair safety barriers, swimming pool fences, safety plugs or bicycle helmets). However, as long as the child depends on the caregiver to shut the stair safety barrier or the swimming pool fence, to put the safety plug on the electrical outlet, or to remind them to wear the bicycle helmet, the study of caregiver behaviour will remain of fundamental importance.

2.3.9 Falling: a review

Falls represent an important cause of injury and death. Estimates for the US indicate that three million children require emergency department care for fall-related injuries of all kinds annually (AAP, 2001). Falling impact accidents may be of very different kinds: from a simple traumatic experience with no physical consequences up to death. Statistics show that some factors are related with higher incidence of falls. These factors will be presented in the next sections.

2.3.9.1 Causes

Falls do not distribute homogeneously throughout the year, as they are prevalent in the summer, nor along the day – falls happen mainly in the afternoon. Presumably because in the summer windows tend to be open, and in the afternoon children tend to be at home. One study (Istre, McCoy, Stowe, Davies, Zane, Anderson, & Wiebe, 2003) refers that in Dallas spring and autumn seasons have a higher incidence of falls than summer, because the heat of summer in Dallas led to an almost universal use of air conditioning, with windows kept closed. They also reported a peak of falls around meal times when supervision might be more careless. These results show that some context-related variables influence the risk of falling, and that includes air temperature, daily routines and other factors.

Falls do not occur equally in both sexes (boys fall more frequently than girls – 50 to 300 % more, according to different reports), and they don't have the same impact in children of different ages. More than 2/3 of all falls occurred in children younger than 5 years of age (Sieben, Leavitt, & French, 1971) and higher mortality rates can be observed at younger ages. In US statistics, ethnicity effects were also observed, probably reflecting life conditions and poverty.

Age seems to be related to the nature of falls, including the places from which children fall. Kindergarten children usually fall from windows, and older boys fall from dangerous areas, such as rooftops and fire escapes (AAP, 2001; Sieben, Leavitt, & French, 1971). This seems to be consistent with the development of judgemental capabilities, since preschoolers don't seem to perceive increased danger at higher elevations, and older children may become less careless when they are playing.
Istre and colleagues (2003) analysed falls from balconies and windows and concluded that for more than two thirds of balcony related falls, the children fell from between the balcony rails, all of which were spaced more than 10 cm apart. Amazingly, more than two thirds of window related falls, occurred in windows lower than 61 cm.

Epidemiologic data rarely refers to the design of the barriers involved in the accidents, and there is no reliable information about detailed characteristics of protection devices. Press clips (see Appendix 2) are more focused on the supervision details about the accident (Was the mother present? Was the kid alone? Was he/she playing under adequate supervision? Was it the first accident? And so on and so forth). No serious analytical information was found in press clips that offered or supported a scientific approach to this matter.

Different studies report some predisposing factors for fall injuries, such as: a history of previous major unintentional injury to the patient or siblings, neurologic disorders, developmental delay or hyperactivity, and documented parental neglect. Families with social and demographic factors such as: poverty, single parent households, inadequate child care, deteriorating housing, overcrowding, family instability, and acute stress factors such as recent moves, illnesses and job changes, seem to be more prompt to this type of accidents (AAP, 2001; Sieben, Leavitt, & French, 1971; Spiegel & Lindaman, 1977; Mayer, Meuli, Lips, & Frey, 2006; Crawley, 1996; Pressley & Barlow, 2007).

Falls happen for a lot a reasons but the association with some consistent causes deserve special attention: family related variables, novelty and variation in daily routines, physical constraints, children's characteristics, and adequate supervision.

Information about the risk of drowning, on the other hand, showed that infants are most likely to drown in bathtubs, toddlers in swimming pools, and other children in other freshwater sites (National Institute of Child Health and Human Development, 2001). It is quite clear that the prevention of drowning is closely connected to the devices that limit access to the water, and that in the case of toddlers the nature and structure of restraining devices must be carefully analyzed. The risk of drowning in bathtubs was also analyzed in the present report, leading to the introduction of barriers that simulated bathtubs height. The main risk in this case was not the risk of falling but the risk of drowning.

2.3.9.2 Consequences

Data from the US Safe Kids Campaign (in AAP, 2001) indicated that falls can account for 9 million treatments in emergency units that do not require hospitalization. Despite these numbers and the fact that falls are the leading cause of injury in children, they are rarely fatal in children. Falls from a second floor or higher (more than 6.7 m) and falls into hard surfaces may lead to death. Many fatalities occur in falls from around 10 m, while falls from first and second floor, although non-fatal, may provoke serious injuries. Falling from balconies and windows are a part of these accidents.

The AAP (2001) has analysed data from the CPSC (US Consumer Product Safety Commission) relative to children who fell from windows in 1993. These data indicate that around 90% of all falls derive from falls of less than 7 m. Nearly 50% of these accidents were classified as “serious” such as fractures, intracranial haemorrhages and internal lesions. The most frequent injuries were head injuries followed by fractures of the extremities (Mayer et al., 2006; Istre et al., 2003; Lallier, Bouchard, St-Vil, Dupont, & Tucci, 1999; Wang, Kim, Griffith, Summers, McComb, Levy & Mahour, 2001; Vish, Powell, Wiltsek, & Sheehan, 2005). Children between 1 and 3 years of age may fall from all storeys. Older children (4-6 yr) fall from smaller heights. This trend may be explained by the fact that younger children cannot fully evaluate the impact of falling from different heights. Older children, on the other hand, can discriminate depth and height more accurately, and, accordingly, they can also anticipate negative impacts of falling from higher places. Risky behaviours in more dangerous conditions are less likely to occur.

In general, falling from greater heights lead to more severe injuries. However, the nature of the surface onto which the child falls and the degree to which the fall is broken on the way down modify the pattern and severity of injuries (Sieben, Leavitt, & French, 1971; AAP, 2001). Even though the potential for serious injury is superior as the height increases, the number of injuries from low-height falls is much greater, presumably due to much larger exposure to this type of danger and perhaps because of poorer precautions (Culvenor, 2002).

The costs of injuries from falls are considerable. Nonfatal injuries in children result in lost time in school, emotional distress and possibly in a lifetime of impaired function and expensive care. Several authors have calculated the economic impact of falls. Total costs are usually very high because they must include emergency room diagnoses and treatment, after-care, rehabilitation (Spiegel and Lindaman, 1977). Falls have also some impact in academic achievement, well-being and social activity.

In Los Angeles County, the annual hospital charges from 1986 to 1988 were more than $600 000, or about $5000 per child admitted with fall-related injury (AAP, 2001). Data from the US (National Hospital Ambulatory Medical Care Survey) for 1992-1994 revealed a national cost of $958 million for emergency care for children who were seen for falls. Although fewer than 3% were falls from extreme heights, they would still account for almost $10 million annually, including 26% paid by Medicaid (AAP, 2001).

The fatal injuries have costs that are not possible to determine, since the loss of a child's potential productivity and creativity has a profound impact on society (Crawley, 1996).

From 1990 to 2000, drowning was the second leading cause of unintentional injury death in the USA, from 1 to 19 years of age (American Academy of Pediatrics, 2003). The AAP recommendations concerning this topic are quite clear: installation of fencing that isolates the swimming pool from the house and yard is effective in preventing more than 50 % of swimming pool drowning among young children. They also mention that no protection device can replace adequate supervision. However, the characteristics and dimensions of such fences were beyond the scope of the report. The present investigation is concerned with the restraining effects of barriers in very young infants from a morphological and behavioural perspective.

3. METHODS

3.1 Participants

Ninety eight children from 9 to 75 months divided by 3 age groups: group 1 (10 children from 9-18 months), group 2 (30 children from 19-36 months) and group 3 (58 children from 37-75 months of age). Sample differences between groups reflect the relevance of the barrier crossing problem at different ages, and that makes the third group the most interesting for the purpose of this study, therefore the bigger one.

3.2 Barriers description

Children of different ages also behave differently. Accordingly, obstacles have to be specified in a distinct way in the three groups, and for each age group different types of barriers were selected (see Table 3).

A total of 13 barriers were tested, following recommendations and standards. Some barriers were not recommended by available norms but seemed adjusted to very young children. Finally, some barriers with standard dimensions and with the upper barriers rotative and backed (i.e., located inwards in relation to the rest of the profile) were analysed.

Table 3. Description of the barriers selected for the different age groups.

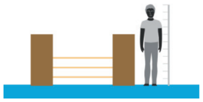
Barrier	Age (months)	Height (cm)	Characteristics	Drawing (reference child 1,10m tall)	Picture
A-1	9-18	39	3 horizontal cylinder bars with gaps of 11 cm between them and a diameter of 2 cm. The purpose of selecting this type of barrier for this age group was mainly to see if children would try to go through the gaps.		
B-1	9-18	30	Vertical wood panel of 30 cm, 2 cm thick, round soft edge at the top. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier.		
C-1 D-2	9-18 19-36	50	Vertical wood panel of 50 cm, 2 cm thick, round soft edge at the top. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier. Children who can cross a barrier this high can get into most bathtubs by themselves. This barrier was included in groups 1 and 2 so that we could analyse the capability of climbing into a bathtub on a developmental perspective.		 

Table 3. Description of the barriers selected for the different age groups (cont.).

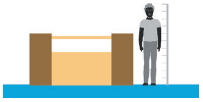
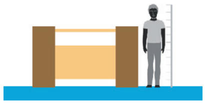
Barrier	Age (months)	Height (cm)	Characteristics	Drawing (reference child 1,10m tall)	Picture
E-2	19-36	67	Vertical wood panel of 45 cm + 18 cm gap + horizontal bar 4 cm high x 2 cm thick. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing through or above the barrier. The gap of 18 cm from a height of 45 cm was selected based on regulations from France (NF P 01-012:1988, currently under revision) adopted by Portugal in 2005 as a voluntary technical specification.		
F-2	19-36	78	11 cm gap + vertical wood panel of 45 cm + 18 cm gap + horizontal bar 4 cm high x 2 cm thick. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing through or above the barrier. The barrier is similar to barrier E-2 but the 18 cm gap is from a height of 56 cm.		

Table 3. Description of the barriers selected for the different age groups (cont.).

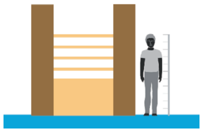
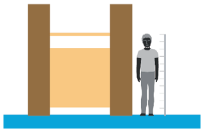
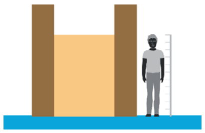
Barrier	Age (months)	Height (cm)	Characteristics	Drawing (reference child 1,10m tall)	Picture
G-3	37-75	110	Vertical wood panel of 50 cm + 4 horizontal bars, 4 cm high x 2 cm thick, with gaps of 11 cm between them. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier. This type of barrier is used in many balconies in different countries.		
H-3	37-75	113	11 cm gap + vertical wood panel of 80 cm + 18 cm gap + horizontal bar 4 cm high x 2 cm thick. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing through or above the barrier. This type of barrier with no horizontal bars was expected to increase time to cross.		
I-3	37-75	110	Vertical wood panel of 110 cm, 2 cm thick, round soft edge at the top. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier. 110 cm is the most frequent height required for guards on balconies and swimming pool barriers.		

Table 3. Description of the barriers selected for the different age groups (cont.).

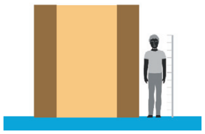
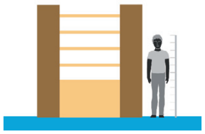
Barrier	Age (months)	Height (cm)	Characteristics	Drawing (reference child 1,10m tall)	Picture
J-3	37-75	150	Wood panel of 150 cm, 2 cm thick, round soft edge at the top. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier. 150 cm is the highest standard recommendation for swimming pool fences.		
K-3	37-75	138	Vertical wood panel of 50 cm + 4 horizontal bars, 4 cm high x 2 cm thick, with gaps of 18 cm between them. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing through or above the barrier. This barrier is similar to barrier G3 but with greater gaps between the horizontal bars. This gap is according to NF P 01-012:1988 (France) and was adopted by Portugal in 2005 as a voluntary technical specification.		

Table 3. Description of the barriers selected for the different age groups (cont.).

Barrier	Age (months)	Height (cm)	Characteristics	Drawing (reference child 1,10m tall)	Picture
L-3	37-75	110	Vertical wood panel of 60 cm + 4 horizontal bars, 4 cm high x 2 cm thick, with the first gap of 8 cm and the other gaps of 5,5 cm + a cylinder rotating rod, with a diameter of 3,5 cm, backing 8,5 cm from the barrier, with a vertical distance of 6 cm and a gap of 10,4 cm from the last bar). The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier despite of the backing rod.		
M-3	37-75	110	Vertical wood panel of 100 cm + a cylinder rotating rod, with a diameter of 3,5 cm, backing 8,5 cm from the barrier, with a vertical distance of 6,5 cm and a gap of 10,7 cm from the panel. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier despite of the backing rod. This barrier should be more difficult to transpose than the previous one because it has no footholds.		

Table 3. Description of the barriers selected for the different age groups (cont.).

Barrier	Age (months)	Height (cm)	Characteristics	Drawing (reference child 1,10m tall)	Picture
N-3	37-75	110	Vertical wood panel of 100 cm + 2 cylinder rotating rods, with a diameter of 3,5 cm, the first one backing 8,5 cm from the barrier, and the second one backing 6,5 cm from the first one, with a vertical distance of 6,5 cm and a gap of 9,19 cm. The purpose of selecting this type of barrier for this age group was to see if children would succeed in passing above the barrier despite of the 2 backing rods. This barrier should be more difficult to cross than the previous one due to the second rod.		

3.3 Anthropometric variables selection

The variables that were chosen to characterize the children's morphology (Table 4) were those that literature underlines as having the greatest influence upon their capacities in these kinds of skills: 1) reaching objects put at a high level and/or climbing barriers (maximum vertical reaching height, upper limb length which means acromiale-radiale length, lower limb length that means trochanterion height and stature), 2) to pass between two obstacles (head circumference, biparietal breadth and anterior-posterior chest breadth), 3) grasping objects and moving the body over the obstacles (hand length which means midstylion-dactylion lenght), strength (handgrip), and body mass (weight).

Table 4 - Anthropometric variables.

Objective	Selected variables
Reaching/ Scaling	Maximum Vertical Reaching Height
	Acromiale-Dactylion Length
	Trochanterion Height
	Stature
Passing Through	Head Circumference
	Biparietal Breadth
	A-P Chest Breadth
Grasping, strength and body mass	Midstylion-Dactylion Length
	Handgrip
	Weight

3.4 Variables description

The anthropometric measures were obtained according to ISAK (2006), with two exceptions - the maximum vertical reaching height and the biparietal breadth, and included: stature, weight, head circumference (HC), biparietal breadth (BB), anterior-posterior chest breadth (APCB), midstylion-dactylion length (MDL), acromiale-dactylion length (ADL), trochanterion height (TH) and maximum vertical reaching height (MVRH).

Figure 2 presents the protocol used to measure the different anthropometric variables selected.

Stature: the child assumes a standing position with the arms hanging by the sides backing the anthropometer, bare-footed with the heels together and the feet extremities separated approximately 60º. Weight must be equally distributed on both feet and the head placed in the Frankfurt plan, which means that the horizontal plan passes through the tragion point (the notch superior to the tragus of the ear) and through the orbitale point (lower edge of the eye socket). At the moment of the measurement the child must adopt an erect position and must inhale deeply (Fig. 2).

Weight: The child, bare-footed and with light clothes, is put on the centre of the weighing scale with his weight well distributed on both feet and looking forward assuming a relaxed standing position with the arms hanging by the sides (Fig. 2).

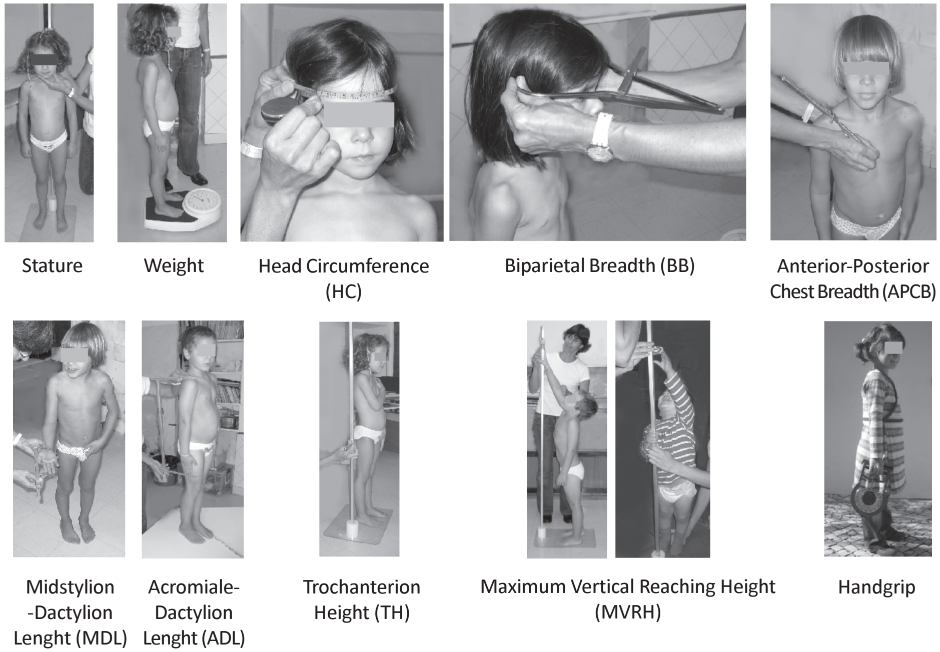


Figure 2 – Anthropometric variables.

Head Circumference (HC): The child assumes a relaxed standing position with the arms hanging by the sides and the head in the Frankfurt plan. The measure is taken perpendicularly to the head longitudinal axis, in the horizontal plan, immediately over the glabella (mid-point between the brow ridges) (Fig. 2).

Biparietal Breadth (BB): The child assumes a relaxed standing position with the arms hanging by the sides and the head in the Frankfurt plan. The measure is taken perpendicularly to the head longitudinal axis, between the most lateral portions of parietal bones (Fig. 2).

Anterior-Posterior Chest Breadth (APCB): The child assumes a relaxed standing position, with the arms hanging by the sides. The measure is taken at end-tidal expiration and obtained between mesoesternale point (point located on the corpus sterni at the level of articulation of the 4th chondrosternal articulation) and the spinous process of the vertebra located at the same level on a plan parallel to the floor, and on the biggest posterior projection point (Fig. 2).

Midstylion-Dactylion Lenght (MDL) – Hand Length: The child assumes a relaxed standing position with the left arm hanging by the side. The right elbow must be slightly flexed, forearm supinated and the fingers extended (but not in hyper-extension). The measure is taken in parallel with the hand´s longitudinal axis between midstylion point (medial point of an imaginary horizontal line localized on the anterior area of the wrist at the level of the stylion, which means the most distal point of the lateral margin of the styloid process of the radius) and the dactylion point (the tip of the middle finger) (Fig. 2).

Acromiale-Dactylion Lenght (ADL) - Upper Extremity Length: The child assumes a relaxed standing position, with the arms hanging by the sides having the hand with its fingers together. One branch of the calliper is held on the acromiale point (the most superior aspect of the most lateral part of the acromion border), while the other branch is placed on the dactylion point (Fig. 2).

Trochanterion Height (TH) - Lower Extremity Length: The child assumes a standing position with his left upper limb along the trunk and the right upper limb flexed over the chest, with the feet together and the weight equally distributed on both feet. The measure is taken from the most superior trochanterion point to the floor (Fig. 2).

Maximum Vertical Reaching Height (MVRH) - The child assumes a standing position, barefooted facing the anthropometer as close as possible. The child must raise his dominant upper limb extended with his hand opened with the fingers together, pushing up, as far as possible, without raising the heels from the floor (Fig. 2).

Handgrip: The child assumes a standing position and takes the dynamometer in the preferred hand. He must squeeze it forcefully (gradually and continuously), at least 2 seconds, holding the dynamometer away from the body. During the test, the arm and hand holding the dynamometer should not touch the body. The instrument is held in line with the forearm and hangs down at the side. The child repeats the test with the non preferred hand (Fig. 2).

The measurement instruments used were a scale – Seca model 761 7019009 from Vogel & Halke (Germany), to determine body mass; an anthropometer from Siber-Hegner GPM (Zurich) to obtain stature and trochanterion height, a large sliding caliper from Siber-Hegner GPM (Zurich) to take lengths (acromiale-dactylion and hand) and breadths (biparietal and A-P chest), an anthropometric tape from Rosscraft to measure the head circumference and a grip strength dynamometer T.K.K. 5001 GRIP A from Takei Scientific Instruments CO, LTD.

3.5 Standard and reference norms

Most part of the published reference norms appear in the ambit of population nutritional status assessment using for this reason, a restrict number of anthropometric measures, particularly the head circumference, recumbent length, standing height, weight, body mass index, waist circumference, mid-arm circumferences, upper arm length, subscapular skinfold thickness, triceps skinfold thickness, maximal calf circumference, upper leg length, mid-thigh circumference. This fact makes the comparison difficult of some of our collected data with the existent norms. In this study we used as comparison terms a national reference norm - RAPIL (Vieira & Fragoso, in press) and three international reference norms - WHO, Euro-Growth 2000 (Haschke, van't Hof & Euro Study Group, 2000) and NHANES 1999-2002 (McDowell, Fryar, Hirsch & Ogden, 2005).

Appendix 3 presents tables with the reference norm values for the percentiles 5, 10, 50, 90 and 95, relatively to each studied variable and for ages between 12 months and 6 years, and the values of mean (M), standard deviation (SD), maximum (MAX) and minimum (MIN) presented by the children in our sample.

3.5.1 Comparison between our children's morphology and the morphology of the children of the reference populations

Being aware that the number of assessed children for each age group is limited and that all the comparisons between our results and the reference populations' are influenced by the individual characteristics of the children of our sample, we still consider the importance of the comparison between our children's morphology and the morphology of the children of the reference populations in order to allow some generalization for the European population.

In what concerns stature we can say that until 3 years the children of our study are generally taller than WHO and Euro Studies; however they are smaller than NHANES. From 4 to 6 years the children in our sample are taller than those averaged in RAPIL.

Considering weight we can declare that our children are in general and for every age heavier than any of the used reference populations. This information must be carefully understood: a number of variables that are closely connected to body weight were not considered.

The head circumferences of the children that we have measured are, for all ages, bigger than WHO children, except for 3 year-old girls, being that the head circumferences are bigger than the children of both sexes of the Euro Study at 2 and 3 years only for girls.

Between 4 and 6 years the upper limbs length (acromial-dactylion lenght) of our children was superior to the RAPIL children, which reflects the bigger stature shown by these children. The comparison concerning the lower limbs (trochanterion height) was not possible because we have used different methods. In RAPIL lower limb length was obtain indirectly through the difference between stature and sitting height, and in our study it was assessed from the trochanterion point to the floor.

Although at the age of 4 years the children of our study have superior thoracic breadth (anterior-posterior chest breadth) when compared with the children of RAPIL, at 5 years of age thoracic breadths are identical in both studies. Regarding this variable, at 6 years the girls of our study have smaller dimensions than those reported in RAPIL, being the boys' dimensions similar for both populations.

In short, the children we have assessed are generally taller and heavier, have longer limbs, larger head circumferences and bigger thoracic breadths than the children of the reference populations we used for comparisons. One of the reasons for the existence of these differences can be explained by the normal tendency of children to present a bigger growth of the linear dimensions (stature and length) and the earlier accumulation of fat mass which has repercussions on weight increase. Bigger children can be favoured in what concerns passing over a barrier, but cannot slide through barriers as easily.

3.6 Task description

Wearing comfortable clothes, children were asked to climb the different types of barriers selected for their age group. The experimental part of the project was developed in the summer and early autumn, and some kids performed the task barefoot. No indications about that detail were given by the experimenters, so children could use or take off their shoes.

Instructions and encouragement was provided by a member of the experimental team, by the day care teacher, or by one of the parents (in the younger group). Most children were filmed in their day care centre, with their teachers/educators nearby, in order to reduce the impact of a non-familiar environment. Informed consent was obtained from the children's parents previous to the study and institutions were fully informed about the nature and purpose of the study.

In groups 1 and 2, different 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.

After 150 s, in groups 1 and 2, the experimenter placed 2 boxes (dimensions 30 cm length x 20 cm width x 10 cm height, and 30 cm length x 20 cm width x 20 cm height) close to the barrier, offering additional but not compulsory aid to cross the barrier. In group 3 the children knew that the boxes were available and could get them whenever they wanted.

The children were taken to the experiment apparatus in small groups. The task was performed by one child at a time. Visual access to other children's trials was allowed.

In all conditions the children were filmed from behind. The video recordings were pasted into movie fragments for analysis. The following items were then considered: 1) success/failure in crossing the barrier (with or without boxes), 2) time to cross the barrier (from the moment of the first contact with the barrier, previous to the climbing action, until contact with the floor on the other side, or until the last visible frame when contact was occluded by the height of the barrier), and 3) passing technique (action modes adopted for transposition).

3.7 Actions modes

The action modes adopted for the crossing of the barrier were classified following the criteria of action control and safety when transposing the barrier. It was assumed that when crossing a barrier with maximum control, children keep their vertical posture, keeping the head above the waist. Arms can move easily and balance when transposing the barrier is not greatly affected. The risk of falling is minimal (see Fig. 3). 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. So, the barrier is crossed with the head and waist at the same level. This technique is more dangerous and guarantees less balance than the previous one (see Fig. 4). The third action mode is the most dangerous one since it is characterized by crossing with the head under the waist. In a way this represents a situation of a probable fall (see Fig. 5). Next, we present some examples of the action modes described.

1 – HOW – Head over waist – the child crosses the barrier with the head higher than the waist (see Fig. 3). This technique demonstrates a better movement control.

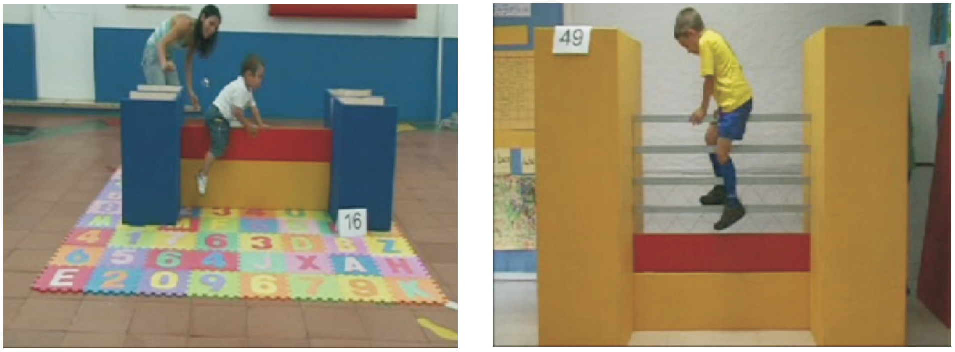


Figure 3 - Action mode 1 (HOW – Head over waist).

2 – HAW – Head and waist - the child crosses the barrier with the head and the waist at the same level (see Fig. 4). Fear and need for safety are evident.

Figure 4 - Action mode 2 (HAW – Head and waist).

3 – HUW – Head under waist - the child crosses the barrier with the head lower than the waist (see Fig. 5). This technique implies a higher risk of head impact and probably expresses a minor control of movement.


Figure 5 - Action mode 3 (HUW – Head under waist).

Sometimes the child exhibited more than one action mode to cross a barrier (e.g., started with head over waist but when the second leg crossed the barrier the head and waist were at the same level). This and other possible mixed action types were registered and classified as "mixed techniques". The 3 main action modes and a mixed one are described in Figure 6, where the whole action sequence may be observed.

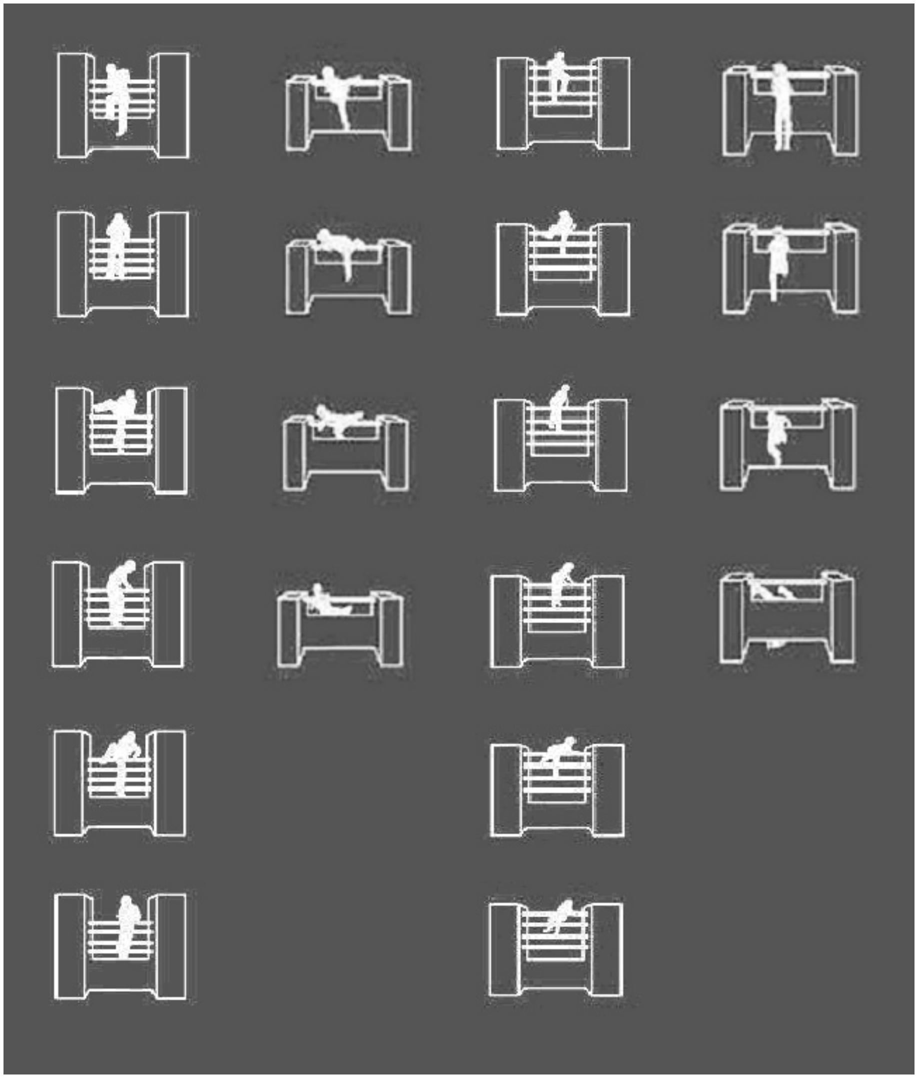


Figure 6 – Sequences of action modes. HOW (left column), HAW (left-center column), HOW to HAW (right-center column), and HUW (right column).

4. RESULTS

4.1 Crossing different barriers: success rate

One of the ways to assess the degree of difficulty is the percentage of success in crossing a barrier.

The crossing of each barrier was tested under 2 different conditions: 1) without any environmental help or 2) with the help of the boxes children could climb into.

The analysis of the frequencies and percentage of success and failure (with no help and with boxes) while crossing different barriers is presented in Appendix 4.

As expected, the percentage of success was different in the 3 age groups. As age increases children seemed to be more skilful in this sort of tasks. In the younger group, 2 barriers could totally prevent crossing and the less complex barrier showed a success rate of only 20% (see figure 7). However, this data should be carefully analysed due to the reduced size of the sample in group 1. In group 2, the most difficult barrier could prevent crossing in 90% of the cases; in the less complex barrier 70% of all children exhibited some sort of crossing technique (see figure 8). 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% (see figure 9), that is, almost everyone could pass it.

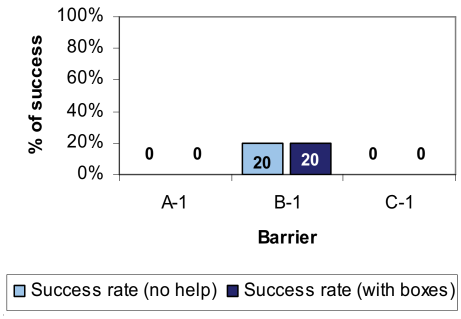


Figure 7 - Percentage of success in crossing the 3 barriers in Group 1.

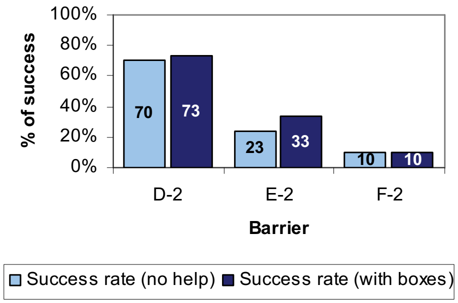


Figure 8 - Percentage of success in crossing the 3 barriers in Group 2.

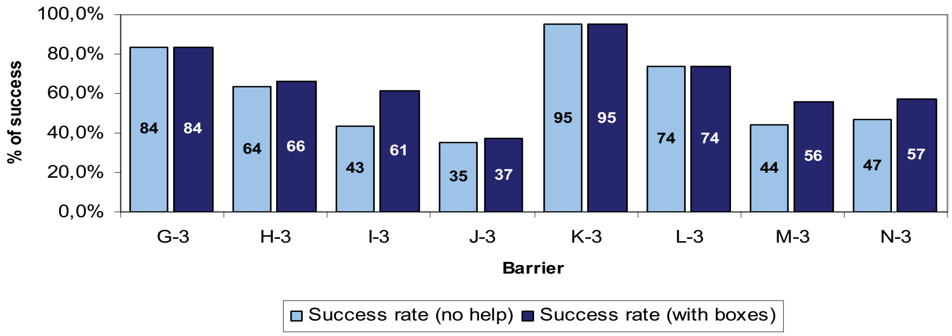
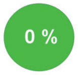


Figure 9 - Percentage of success in crossing the 8 barriers in Group 3.

By analysing the success rate in the different barriers we can verify that the boxes were used mainly in the barriers that had no footholds (e.g., I-3, M-3, N-3) when children perceived that by using the boxes they would have an advantage. In barrier J-3 (1,50 m panel) the boxes didn't seem to bring any advantages since, even with boxes, most children wouldn't be able to reach the top of the barrier. This is probably why most children didn't use the boxes in that situation. When the barriers are easy to climb (e.g., G-3, K-3, L-3) the children don't need to get the boxes to help the action of crossing. In terms of child safety, we can conclude that parents and caregivers should pay special attention to small climbable objects that can be placed near barriers, specially if the barriers are more difficult to climb. When the barriers are easy to climb the surveillance must be strengthened but the children will not need to have any extra help to climb them if they want to. Boxes, chairs, other pieces of furniture, or even friends can act as action encouragement devices or enablers (see Fig. 10).

Figure 10 – Friends can encourage and help to cross a barrier.

In order to evaluate barrier resilience by age group we have grouped all crossings in 6 groups:



No children in the age group crossed this barrier

Up to 25% of the children crossed this barrier

Between 25% and 50% of the children crossed this barrier

Between 50% and 75% of the children crossed this barrier

Between 75% and 99% of the children crossed this barrier

All the children crossed this barrier.

The results of this analysis are presented in Tables 5 and 6.

Table 5 - Grouping crossings for 9-36 months. Six success levels were considered.

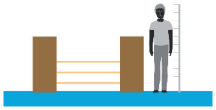
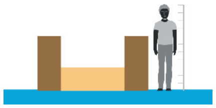
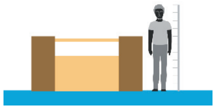
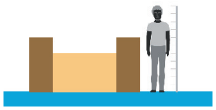
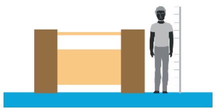
Barrier (reference child 1,10m tall)	Age (months)	Success	Barrier (reference child 1,10m tall)	Age (months)	Success
 A-1	9-18	0 %	 D-2	18-36	75 %
 B-1	9-18	25 %	 E-2	18-36	25 %
 C-1	9-18	0 %	 F-2	18-36	25 %

Table 6 - Grouping crossings for 36 months and older. Six success levels were considered.

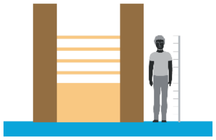
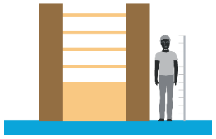
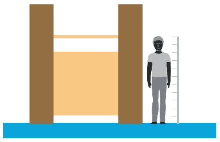
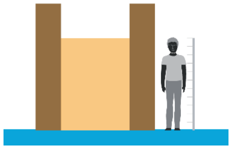
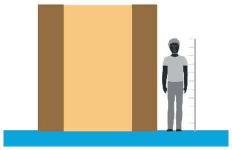
Barrier (reference child 1,10m tall)	Age (months)	Success	Barrier (reference child 1,10m tall)	Age (months)	Success
 G-3	36-48	75 %	 K-3	36-48	100 %
	48-60	50 %		48-60	100 %
	60-72	100 %		60-72	100 %
	> 72	100 %		> 72	100 %
 H-3	36-48	25 %	 L-3	36-48	50 %
	48-60	75 %		48-60	100 %
	60-72	100 %		60-72	100 %
	> 72	100 %		> 72	100 %

Table 6 - Grouping crossings for 36 months and older (cont.)

Barrier (reference child 1,10m tall)	Age (months)	Success	Barrier (reference child 1,10m tall)	Age (months)	Success
 I-3	36-48	25 %	 M-3	36-48	0 %
	48-60	25 %		48-60	50 %
	60-72	75 %		60-72	75 %
	> 72	100 %		> 72	100 %
 J-3	36-48	0 %	 N-3	36-48	25 %
	48-60	0 %		48-60	50 %
	60-72	50 %		60-72	50 %
	> 72	100 %		> 72	100 %

4.2 Crossing different barriers: measuring the time to cross

When the crossing of barriers is not prevented for all children, from a child safety point of view it's important to investigate their 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 and we also considered the percentage of success according to different time categories. These categories mirror different periods of lack of adult supervision that might exist, accordingly to the daily activity the adult might be involved in. Finally, we examined the correlation between time to cross and different anthropometric variables, in order to determine which variables seem to be more relevant to barrier crossing.

Table 7 - Time to cross different barriers in Group 3– best climbers. Data was ranked and the best 15 subjects in each barrier were selected for analysis.

Barrier	Time to cross of the 15 best climbers (in seconds)			
	Mean	SD	Min	Max
G-3	6,60	1,30	4	9
H-3	10,93	3,39	5	17
I-3	9,13	3,94	3	14
J-3	14,33	7,39	6	36
K-3	7,60	1,84	4	10
L-3	10,80	4,28	4	18
M-3	6,87	2,95	3	12
N-3	8,80	3,59	2	12

4.2.1. Time the best climbers take to cross different barriers

Each barrier was crossed by a different number of children (from 15 to 41 in group 3). The most difficult barriers were crossed only by the most skilful climbers but the easiest barriers were crossed by good and bad climbers. In order to avoid 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 time to cross. This analysis refers only to group 3 since in groups 1 and 2 the number of children that crossed some barriers was too small for testing. The results are shown in Table 7.

Mean time to cross was always less than 15 seconds, and only three barriers were able to limit the action of crossing for more than 10 seconds. These values clearly reflect the idea that there are no absolute safe barriers. When considering children with a high skill level, the maximum time to cross the most demanding barrier was 36 seconds, and that subject was, for sure, an outlier.

4.2.2. Percentage of crossings according to different time categories

When children are nearby risky environments, such as stairs, balconies or swimming pools, they are usually supervised by an adult. However, since risky environments are frequently equipped with different kinds of barriers or restraining devices to avoid children's access to them, short periods of lack of attention might exist if, for example, the adult is involved in some other kind of activity. In this investigation, we selected different time categories related to different daily activities as shown in Table 8.

Table 8 - Average time needed to perform different daily activities.

Action	Drawing	Time to perform the action
Turning on the TV and switching between 3 channels to check what's on		20 seconds
Filling a 1,5 L bottle of water		30 seconds
Reading one page of a book		60 seconds
Brushing teeth		120 seconds

Of all the successful crossings in our study, 191 (77,3%) occurred in less than 20 seconds, 41 (16,6%) took less than 30 seconds and 14 (5,7%). Only one episode lasted more than 1 minute (see Fig. 11).

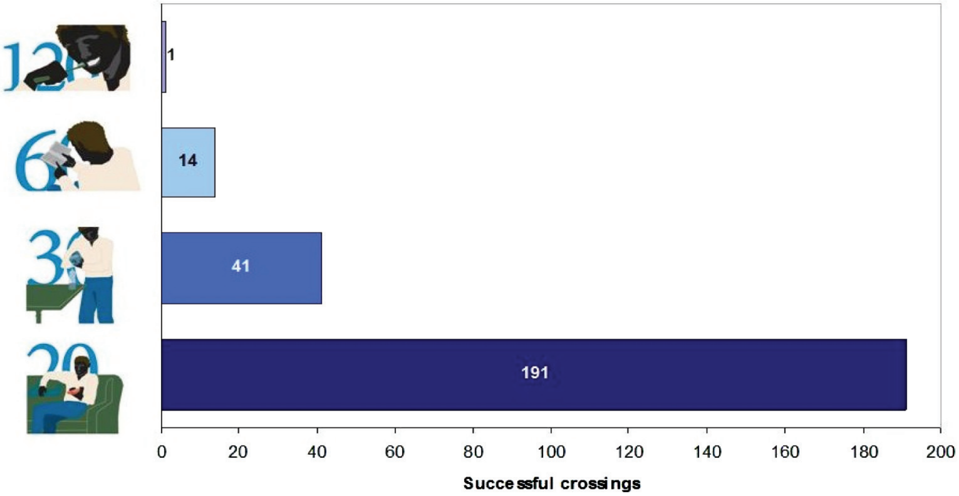


Figure 11 - Successful crossings by time category.

Subsequently, we analysed the percentage of crossings that occurred in each time category for the different barriers. This analysis was limited to groups 2 and 3 since in group 1 the number of crossings was very limited. We also excluded from analysis all the crossings that were made with the help of the boxes, since time to get the boxes or some other kind of help to cross might vary accordingly to each environment.

4.2.2.1. Percentage of crossings according to different time categories in Group 2

In group 2 most barriers were crossed in less than 20 seconds by the great majority of children (see Fig. 12). All the children that crossed the most difficult barriers in this group (i.e., barrier E-2 and barrier F-2) did so in less than 20 seconds. Barrier D-2 was crossed by a greater number of children (70% of success), so the difference in skill levels was probably greater. In this barrier a few children took more than 20 seconds to cross.

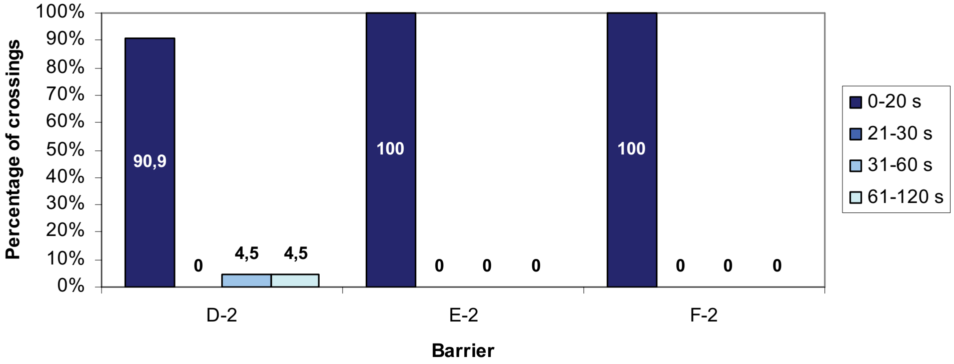


Figure 12 - Percentage of crossings according to different time categories in Group 2.

4.2.2.2. Percentage of crossings according to different time categories in Group 3

All the children that crossed the different barriers in group 3 did it in less than 1 minute, and the great majority of them did it in less than 20 seconds (see Fig. 13). Once again children that climbed the barrier with the lowest success rate in crossing (i.e., barrier J-3), seem to be the most skilled (93,3% performed the task in less than 20 seconds). On the other hand, in the easiest barrier to climb (i.e., barrier K-3 which had a success rate of 95,3%) the difference of skill levels between the climbers is more notorious, since only 63,4% of the crossings took less than 20 seconds.

In group 3, the great majority of children easily crossed all barriers. Time to cross rarely exceeds 20 seconds. Even the highest and more sophisticated barriers couldn't delay the action of crossing in such a way that allowed for parental intervention. In group 2, from 18 to 36 months, the most efficient barrier prevented crossing in 90 % of the attempts.

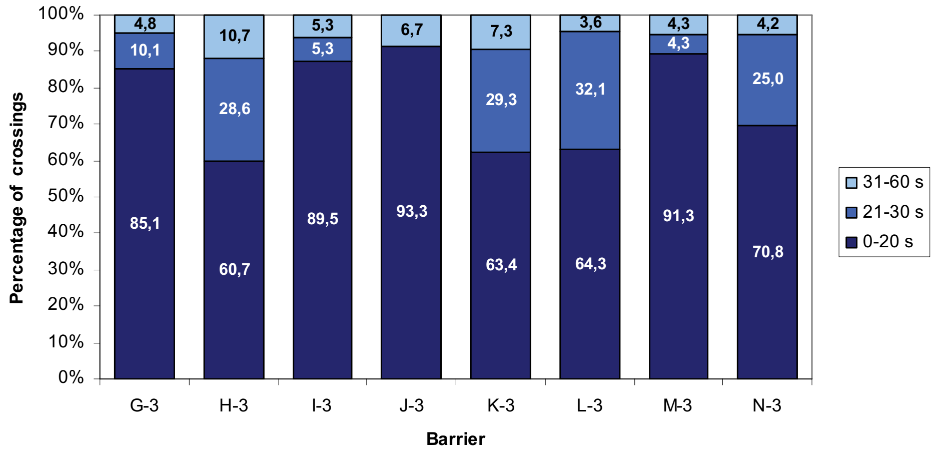


Figure 13 - Percentage of crossings according to different time categories in Group 3.

4.3 Influence of morphological variables

In order to determine the influence of morphological variables in the action of crossing the barriers we analysed: i) the relationship between these variables and success in crossing, ii) the relationship between these variables and time to cross.

4.3.1 Relationship between morphological variables and success in crossing different barriers

The comparison between the morphological characteristics of the group of children that crossed each barrier versus the group that couldn't cross was only performed when both groups had at least 20 % of the total sample. For this reason, we excluded from analysis barriers F-2 (which only 10% of the children were able to cross), and G-3 and K-3 (which, respectively, only 16,3% and 4,7% of the children were not able to cross). We also excluded group 1 from analysis due to the small success rate in that group.

Data relative to the comparison of different morphological characteristics in children that failed versus children that succeeded in the action of crossing each barrier are shown in Tables 9 to 16. Table 17 summarizes the significant differences found for the barriers analysed in group 3.

Table 9 - Influence of morphological characteristics in crossing barrier D-2 (* p<0.05).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	2,21	,41	2,39	,33	28	-1,30	-	,203
Stature	85,07	5,73	89,37	4,68	24	-1,88	-	,073
Weight	13,33	2,01	13,82	1,92	24	-,535	-	,598
BMI	18,37	1,58	17,24	1,31	24	1,76	-	,091
ADL	34,58	3,05	37,29	2,29	-	-	25,50	**,016***
TH	38,12	3,33	41,37	3,30	-	-	25,50	**,036***
MVRH	99,75	8,66	104,52	7,92	24	-1,27		,217
HC	48,62	,87	48,70	2,27	-	-	40,00	,222
BB	13,30	,49	12,83	,50	24	2,05	-	,052
APCB	11,77	,73	11,67	,68	24	,299	-	,767
MDL	9,83	,73	10,36	,63	24	-1,73	-	,097

Table 10 - Influence of morphological characteristics in crossing barrier E-2 (* p<0.05).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	2,26	,36	2,60	,22	28	-1,30	-	**,025***
Stature	87,82	5,22	89,87	5,07	-	-	47,50	,272
Weight	13,71	1,69	13,69	2,56	24	-,535	-	,977
BMI	17,75	1,24	16,83	1,80	24	1,76	-	,149
ADL	36,42	2,83	37,33	2,30	-	-	53,00	,435
TH	40,15	3,55	41,87	3,38	24	-2,11	-	,279
MVRH	102,34	8,54	106,34	6,80	-	-	45,50	,225
HC	49,00	,87	47,81	3,68	-	-	66,00	,977
BB	13,04	,50	12,66	,55	24	2,05	-	,106
APCB	11,78	,62	11,44	,83	24	,299	-	,256
MDL	10,14	,67	10,51	,69	24	-1,73	-	,217

Table 11 - Influence of morphological characteristics in crossing barrier H-3 (* p<0.05).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	4,41	,74	5,32	,75	-	-	86,50	**,001***
Stature	105,26	6,21	112,78	7,67	42	-3,34	-	**,002***
Weight	16,91	2,73	20,63	3,89	-	-	90,50	**,001***
BMI	15,19	1,36	16,09	1,48	42	-1,99	-	,053
ADL	44,25	3,03	48,06	3,48	42	-3,65	-	**,001***
TH	51,51	3,90	56,03	4,69	42	-3,26	-	**,002***
MVRH	129,97	8,73	141,14	9,82	42	-3,77	-	**,000***
HC	50,54	1,36	51,20	1,97	42	-1,69	-	,098
BB	13,66	,65	13,84	,54	42	-,957	-	,344
APCB	12,46	,70	12,76	,65	42	-1,44	-	,157
MDL	11,61	,80	12,59	,88	42	-3,65	-	**,001***
Strength	6,08	2,86	9,31	3,22	42	-3,24	-	**,002***

Table 12 - Influence of morphological characteristics in crossing barrier I-3 (* p<0.05).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	4,52	,73	5,60	,61	-	-	60,00	**,000***
Stature	106,40	6,11	114,83	7,73	42	-4,04	-	**,000***
Weight	17,65	2,95	21,42	4,08	42	-3,56	-	**,001***
BMI	15,50	1,52	16,10	1,41	42	-1,33	-	,191
ADL	44,75	2,93	49,20	3,28	42	-4,74	-	**,000***
TH	52,18	3,86	57,29	4,66	42	-3,99	-	**,000***
MVRH	131,68	8,57	144,18	9,33	42	-4,62	-	**,000***
HC	50,75	1,25	51,24	1,30	42	-1,25	-	,218
BB	13,75	,56	13,81	,61	42	-,323	-	,749
APCB	12,51	,69	12,85	,62	42	-1,68	-	,100
MDL	11,79	,83	12,82	,84	42	-4,05	-	**,000***
Strength	6,41	2,52	10,50	3,12	42	-4,70	-	**,000***

Table 13 - Influence of morphological characteristics in crossing barrier J-3 (* $p<0.05$).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	4,54	,75	5,77	,35	40,64	-7,31	-	**,000***
Stature	106,21	6,14	117,26	6,16	41	-5,61	-	**,000***
Weight	17,60	2,91	22,60	3,59	-	-	52,00	**,000***
BMI	15,51	1,44	16,36	1,41	-	-	149,50	,123
ADL	44,87	3,01	50,07	2,74	41	-5,56	-	**,000***
TH	51,97	3,86	58,75	3,53	41	-5,65	-	**,000***
MVRH	131,73	8,58	147,07	7,23	41	-5,89	-	**,000***
HC	50,79	1,34	51,41	1,02	41	-1,54	-	,130
BB	13,75	,59	13,79	,58	41	-,215	-	,831
APCB	12,51	,66	13,01	,55	41	-2,51	-	**,016***
MDL	11,79	,78	13,10	,69	41	-5,42	-	**,000***
Strength	6,58	2,72	11,07	2,69	-	-	41,50	**,000***

Table 14 - Influence of morphological characteristics in crossing barrier L-3.

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	4,64	,77	5,04	,72	36	-1,48	-	,147
Stature	107,03	5,74	110,95	7,68	36	-1,47	-	,151
Weight	17,65	3,01	19,73	3,53	36	-1,65	-	,107
BMI	15,32	1,59	15,90	1,13	36	-1,24	-	,222
ADL	45,02	3,16	47,20	3,35	36	-1,79	-	,082
TH	52,34	4,01	54,73	4,66	36	-1,44	-	,159
MVRH	132,48	8,75	138,23	9,57	36	-1,67	-	,105
HC	50,89	1,45	51,06	1,26	36	-,345	-	,732
BB	13,65	,65	13,77	,60	36	-,521	-	,605
APCB	12,47	,90	12,77	,62	12,16	-,938	-	,345
MDL	11,92	,69	12,38	,83	36	-1,54	-	,131
Strength	7,14	2,46	9,16	3,40	-	-	84,50	,176

Table 15 - Influence of morphological characteristics in crossing barrier M-3 (* p<0.05).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	4,68	,74	5,53	,48	-	-	122,00	**,000***
Stature	108,61	9,37	115,00	6,79	-	-	166,00	**,002***
Weight	18,08	3,10	21,25	3,67	-	-	176,00	**,004***
BMI	15,31	1,72	15,96	1,37	-	-	288,00	,402
ADL	45,43	3,11	49,59	2,90	50	-4,93	-	**,000***
TH	52,56	3,87	57,50	3,90	50	-4,56	-	**,000***
MVRH	133,21	8,78	144,43	8,02	50	-4,75	-	**,000***
HC	50,94	1,59	51,28	1,09	49,07	-,894	-	,376
BB	13,69	,62	13,86	,56	50	-,982	-	,331
APCB	12,57	,70	12,93	,63	50	-1,92	-	,061
MDL	11,97	,83	12,84	,77	50	-3,90	-	**,000***
Strength	7,17	2,76	10,01	3,01	-	-	147,50	**,002***

Table 16 - Influence of morphological characteristics in crossing barrier N-3 (* p<0.05).

Variable	Failure		Success		DF	T	U	p
	M	SD	M	SD				
Age	4,78	,74	5,34	,69	-	-	185,00	**,009***
Stature	108,97	9,45	114,33	7,52	-	-	183,00	**,008***
Weight	18,07	3,00	21,20	3,76	-	-	170,00	**,004***
BMI	15,22	1,74	16,10	1,29	-	-	243,00	,126
ADL	45,47	3,06	49,34	3,24	49	-4,38	-	**,000***
TH	52,83	3,91	56,81	4,49	49	-3,38	-	**,001***
MVRH	133,26	8,69	143,75	8,90	49	-4,26	-	**,000***
HC	50,93	1,52	51,36	1,17	49	-1,13	-	,265
BB	13,69	,61	13,83	,59	49	-,835	-	,408
APCB	12,59	,71	12,93	,60	-		221,50	**,053***
MDL	11,91	,79	12,88	,75	49	-4,50	-	**,000***
Strength	7,02	2,64	10,12	2,99	49	-3,86	-	**,000***

Table 17 - Morphological variables – comparisons between children that can and that cannot cross different barriers (* p<0.05).

Variable	Barrier H-3	Barrier I-3	Barrier J-3	Barrier L-3	Barrier M-3	Barrier N-3
Age	**,001***	**,000***	**,000***	,147	**,000***	**,009***
Stature	**,002***	**,000***	**,000***	,151	**,002***	**,008***
Weight	**,001***	**,001***	**,000***	,107	**,004***	**,004***
BMI	,053	,191	,123	,222	,402	,126
ADL	**,001***	**,000***	**,000***	,082	**,000***	**,000***
TH	**,002***	**,000***	**,000***	,159	**,000***	**,001***
MVRH	**,000***	**,000***	**,000***	,105	**,000***	**,000***
HC	,098	,218	,130	,732	,376	,265
BB	,344	,749	,831	,605	,331	,408
APCB	,157	,100	**,016***	,345	,061	**,053***
MDL	**,001***	**,000***	**,000***	,131	**,000***	**,000***
Strength	**,002***	**,000***	**,000***	,176	**,002***	**,000***

Age, stature, weight, ADL, TH, MVRH, MDL and Strength seem to be determinant for the action of crossing in most barriers. Success in crossing Barrier L-3, the first one presented with the cylinder rotating backing rod, doesn't seem to be related to any of the studied variables. This particular task may involve two components: an easy one, that is just climbing a natural bars structure, and a hard one, that is passing over a rotating bar backing from the barrier. As a new complex task it may involve cognitive processing (how to deal with a rotating bar) and morphology may have little influence. Performance in this kind of tasks may well be of a cognitive nature rather than of a motor one.

The influence of anthropometric variables is quite clear in Fig. 14 where we can see as the relationship between stature and barrier's total height varies among children, conditioning the effort each child has to make to reach the top of the barrier.

Figure 14 – Three children with different relationships between stature and total height of barrier J-3.

4.3.2 Relationship between morphological variables and time to cross different barriers

Some individual characteristics of the children, such as age, body dimensions and strength, influence their ability to climb. It would be expected that older, taller and stronger children took less time to cross most barriers than younger, shorter and weaker children. In order to verify this assumption, we analysed the correlations between those characteristics and time to cross different barriers (see Table 18).

Table 18 - Correlations between time to cross different barriers and anthropometric variables (* p<0.05).

	Time G-3	Time H-3	Time I-3	Time J-3	Time K-3	Time L-3	Time M-3	Time N-3
Age	**-,349***	-,261	**-,522***	,215	**-,537***	**-,502***	-,324	-,309
Stature	-,289	**-,374***	**-,537***	,091	**-,496***	**-,516***	**-,610***	**-,497***
Weight	-,312	-,295	-,397	,154	**-,376***	**-,472***	**-,603***	**-,417***
BMI	-,235	-,048	-,085	,154	,059	-,152	-,375	-,102
ADL	-,296	**-,438***	**-,590***	-,086	**-,486***	**-,581***	**-,565***	**-,527***
TH	-,280	**-,393***	**-,477***	,129	**-,492***	**-,524***	**-,497***	**-,527***
MVRH	-,304	**-,399***	**-,598***	-,063	**-,538***	**-,610***	**-,613***	**-,529***
HC	,008	-,371	**-,477***	-,043	-,162	-,342	-,251	-,035
BB	,040	-,123	-,411	-,047	-,101	-,349	,082	-,201
APCB	-,067	**-,478***	-,286	-,008	-,040	-,219	**-,465***	-,160
MDL	**-,398**	**-,439***	**-,540***	-,441	**-,452***	**-,483***	**-,623***	-,382
Strength	-,265	**-,438***	-,465	,185	**-,517***	**-,532***	**-,592***	-,367

As we can see from the analysis of table 18, time to cross most barriers is inversely correlated with: age, stature, ADL, TH, MVRH, MDL and strength. So, we can conclude that, in general, as children grow older and stronger, with bigger stature, bigger arms, legs and hands, and a bigger maximum vertical reaching height, their time to cross most barriers decreases. Barriers G-3 and I-3 seem to be exceptions to this rule. Barrier G-3 was the first one presented to the children. Age seemed to be determinant for the time to cross since older children took less time to cross, however, most body dimensions were not relevant in that barrier, probably due to its easily climbable design (with horizontal bars). In barrier J-3 no variable seemed to be determinant for the time needed to cross. J-3 was the most difficult barrier to cross, the few children who could cross it were tall and strong enough to jump and hold on to the top (1,50 m), pull themselves up using their arms and throwing one leg over the edge of the horizontal support to pass to the other side. Anthropometric characteristics of these children were probably very similar and none of those characteristics seems to have influenced time to cross. An alternative explanation is that the difficulty level of the J-3 barrier may cause the climbing skills of children to be more influential than their anthropometric characteristics in regards to the time in which they cross.

The relationship between strength and weight (relative strength) was investigated (see Fig. 15).

The strength/weight ratio seems to be an important indicator of climbing competence, since the ability to move over a barrier involves the capacity of supporting body weight for long periods and the power to elevate trunk and legs using arms. Great increments were observed until 5 years of age, followed by a relative conservation of this ratio. This trend may indicate that older children are more predictable, while younger children can rapidly develop new and unpredictable climbing skills.

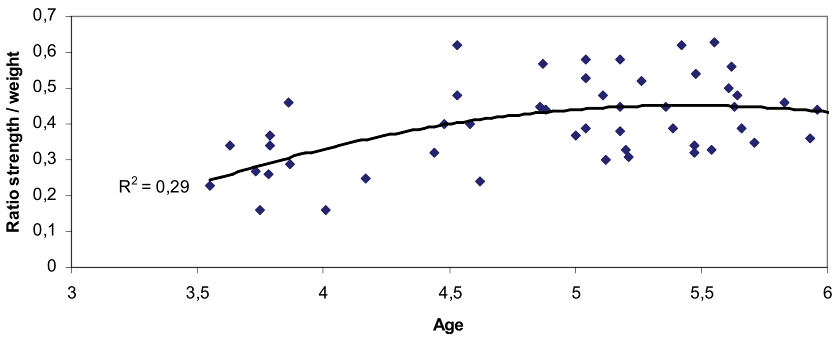


Figure 15 – Relationship between age and ratio strength/weight in group 3.

As we can see, it's clearly easier for older children to elevate their own bodies, since the ratio strength/weight increases as age progresses. As a matter of fact, around 30% of the relationship between strength and weight is explained by age (R^2=0,29).

To better illustrate these differences we divided group 3 in 3 age subgroups (mean ages of 4,11 years, 5,18 years and 5,83 years) (Fig. 16). As we can see, the ratio strength/weight increases from 0,34 in the youngest subgroup to 0,45 in the eldest one, making the task of lifting the body over an object a much easier one.

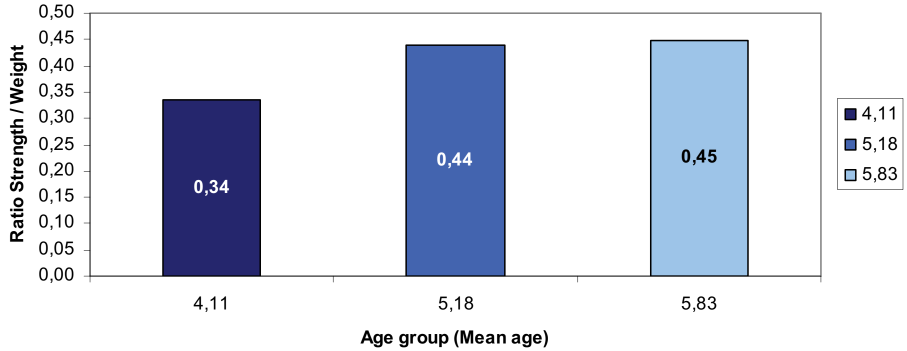


Figure 16 – Ratio strength/weight in 3 age subgroups of Group 3.

To better comprehend the influence of morphological variables on time to cross different barriers we selected the 15 best climbers for each barrier in Group 3 and performed a linear regression stepwise, entering as independent variables the ones we identified as relevant for the action of crossing in most barriers (i.e., age, stature, weight, ACL, TH, MVRH, MDL and strength). In Barriers H-3, J-3, K-3, L-3 and M-3 no significant predictors of time to cross were found. The results for the other barriers are shown in Table 19.

Table 19 - Predictors of time to cross for barriers G-3, I-3 and N-3.

Barrier	Predictors	R Square
G-3	Strength	,444
I-3	MVRH / ADL	,751
N-3	MVRH	,394

4.4 Selected comparisons between barriers

In order to determine the influence of different barrier characteristics in time to cross, we have compared 7 pairs of barriers as shown in Table 20. We selected barriers with similar general characteristics, that were tested in group 3 and that were possible to be compared.