

Child pedestrian anthropometry: evaluation of potential impact points during a crash

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Abstract

This paper highlights potential impact points of a child pedestrian during a crash with a front end of a vehicle. Child anthropometry is defined for ages between 3 and 15 years. It is based on the measurement of 7 different segment body heights (knee, femur, pelvis, shoulder, neck, chin, vertex) performed on about 2000 French children. For each dimension, the 5th, 50th and 95th percentile values are reported and the corresponding linear regression lines are given. Then, these heights are confronted with three different vehicle shapes corresponding to a passenger car, a sport utility vehicle and a light truck in order to identify impact points. In particular, it is shown that the thigh is directly hit by the bumper for children above 12 years old whereas head impacts principally the hood. Influences of the child anthropometry on the pedestrian trajectory and comparison with tests procedure in regulation are also discussed.

Keywords : child, anthropometry, pedestrian, vehicle shape, accident

1 Introduction

In the field of road safety, pedestrian-vehicle crashes are responsible for more than a third of all traffic related fatalities and injuries worldwide (Crandall et al., 2002). This percentage is about 15% in Europe and 11.3% in France (ONISR, 2005). These numbers represent more than 5 600 deaths in the European Community and more than 800 in France.

Among these pedestrian accidents, most of them concern elderly people aged above 70 and children under 15 years old (Berg et al., 2000; Fontaine and Gourlet, 1997). If adults have higher risk of severe injury and mortality, children have an over-risk as noted by Henary et al. (2003). Indeed, Mizuno (2005a) reported that this population represents between 20% and

30% of pedestrian crashes in US, Germany, Japan and Australia. Child mortality comprises in all 25 000 victims in the USA (Hotz et al., 2004) and 700 in Europe (ONISR, 2005). The age group 5-10 seems to be more specifically injured (Fontaine and Gourlet, 1997; Hotz et al., 2004; Pitt et al., 1990) and vulnerable because in particular of their small physical size and their undeveloped abilities for dealing with traffic situations, such as the cognition (attention focus, interpreting traffic signs) or the perception (locating signs, judging speed, peripheral vision) (Cross and Hall, 2005; Schieber and Vegega, 2002).

Epidemiology studies of pedestrian accidents show that the main injuries observed on adults are located on the lower limb (tibia) and the head (Mizuno, 2005a). Injuries to the head are the major causes of pedestrian fatalities, whereas injuries to the lower extremities are usually non fatal (Liu and Yang, 2002b). Injuries identified on children are nearly the same. If the head represents the main injured body part, as far as the leg is concerned, it appears there are more upper leg injuries such as pelvis or femur fractures (Ashton, 1982; Mizuno, 2005a). Lethal injuries concern principally the head segment and the chest (Harruf et al., 1998) and the injury severity is principally linked to the vehicle impact speed (Liu and Yang, 2003).

Obviously, these injuries are correlated with the scenario and the configuration of the accidents. For both adults and children, it has been shown that the main configuration of accidents is described as the pedestrian being impacted by the front end of the car (Henry et al., 2003; Liu et al., 2002a; ONISR, 2005). This configuration is generally encountered when the child or the adult crosses the road and a passenger car impacts him (Brenac et al., 2003; Fontaine and Gourlet, 1997; Harruf et al., 1998).

If we focus on this configuration, it is commonly considered that the pedestrian has a wrap trajectory along the front end of the car (Crandall et al., 2002; Okamoto et al., 2003; Ravani et al. 1981; Roudsari et al., 2005; Serre et al., 2007; Yang et al., 2000). Thus, the pelvis, the abdomen, the thorax and the head wrap around the hood and the windscreen while the lower

legs and the feet wrap underneath the bumper. This trajectory corresponds to the different impact points of the pedestrian with the vehicle. For adults, it has been shown that the major impact points are the leg (at the knee level) against the bumper, the pelvis against the low bonnet and the head against the bonnet or the windscreen (Crandall et al., 2002; Liu and Yang, 2002b; Okamoto et al., 2003; Roudsari et al., 2005). It has been also proved that these impact points depend on two principal parameters: the anthropometry of the pedestrian and the front shape of the vehicle (Liu and Yang, 2002b; Okamoto et al., 2003; Robertson, 1990). In particular, Roudsari et al. (2005) highlight the effect of the vehicle type (passenger car vs. light truck) on crash trajectory and on the consequent source and severity of pedestrian injuries. They demonstrate in particular the importance of the relationship between the pedestrian's centre of gravity and the wrap transition point on the striking vehicle for the vehicle-pedestrian trajectory: carried, thrown forward, knocked down, wrapped around the top.

The aim of this paper is so to confront child anthropometry with three vehicle shapes in order to identify potential injuries on children when they are impacted by the front end of a car. In the Malek et al. (1990) classification, this study has to be considered as a research dealing with countermeasures to prevent child pedestrian injuries during a crash.

This work is divided into two steps. The first one is the acquisition of child anthropometry in pedestrian posture for children aged from 3 to 15 years. The second step consisted in confronting child morphology with front end shapes of different vehicles in order to highlight probable impact points of the pedestrian on the car.

2 Methods

2.1. Child anthropometry

In order to describe the child morphology in pedestrian posture for different ages, anthropometric measurements have been performed on a child population. It has been chosen to consider children from 3 to 15 years old because they represent the overall part of the child population likely to be involved in a pedestrian accident. Moreover, it has been proved that children reach 90% of their adult height by age 14 (Needlman, 2000).

About 2000 French children have been measured. The sample is constituted by 941 boys and 972 girls (sex ratio 0.97) coming largely from south of France (suburb of Marseilles).

Measurements have been performed in paediatrics services of Marseilles' hospitals and in different schools. Children have been measured in agreement with their parents, themselves and a paediatric doctor or school headmaster. Data anonymity has been respected.

Distribution of the sample in function of ages is illustrated Fig. 1. Children have been grouped into 12 classes corresponding to 1 year.

Because it has appeared important to have a good knowledge of the heights of the different body segments, it has been chosen to consider 7 heights. All of these heights correspond to articulations between segment bodies: the knee, the hip (two heights), the shoulder, the neck, the chin and the top of the head (stature). Heights have been taken manually using a classical measuring apparatus (precision 1mm). Children were in standing position against a wall, feet joined without shoes and looking horizontally in order to have the head in right position, arm along the trunk (see Fig. 2).

Weight has also been taken using a classical balance with a precision of 0.1 Kg.

In order to have reproducible and repeatable measurements, dimensions have been based on palpable points on the skeleton. These anatomical points represent reference marks associated to each articulation. For the knee, it has been considered the popliteal space, for the hip the

great trochanter and the superior iliac crest, for the neck the C7 vertebra, for the shoulder the acromion and for the head the chin (gnathion) and the vertex. Heights correspond to the distances between the floor and these points in standing posture. Fig. 2 illustrates all of these measurements.

For each dimension, the equation of the linear regression as a function of age has been computed as $y = a * x + b$ (1) where y is the value of the dimension, a the slope of the equation, x the age of the child stated in years ($3 \leq x \leq 15$), b the intercept of the regression line.

The corresponding determination coefficient (r-squared value) has been also calculated. This coefficient gives the percentage of explicated variable.

For each dimension and for each age class, the 5th, 50th and 95th percentiles values have been calculated in order to compare with other anthropometric database.

2.2. Vehicle shapes and impact points computing

Three different shapes of vehicle have been considered. They correspond to the categories used by the international IHRA consortium especially for the pedestrian group (Mizuno, 2005a). They have been defined to be representative of a middle Light Vehicle (LV), a middle Sport Utility Vehicle (SUV) and a middle Light Truck (LT) in order to study the influence of the vehicle shape. Six parameters have been used to characterize the front end shape: the bumper lead (BL), the bumper centre height (BCH), the leading edge height (LEH), the bonnet length (BON L.), the bonnet angle (BON A.) and the windscreen angle (WIN A.). Mean values of these parameters for the three geometries of front end considered in this study are described in Fig. 3 according to Mizuno (2005a).

To identify the potential injuries on the child pedestrian, the different impact points have been evaluated on the front end of the car. For the knee and the pelvis it has been compared

respectively their height with the bumper height and the low bonnet height (LEH).

Concerning the shoulder, the neck and the head impact, they have been estimated using the WAD (Wrap Around Distance) definition. This value corresponds to the distance between the floor and the body impact on the car along the shape of the vehicle (Okamoto et al., 2003). It is associated to the wrap trajectories of the body on the vehicle and characterises the highest impacts.

The WAD of the head is usually associated to a WAD ratio corresponding to the value equal to the WAD distance divided by the stature of the pedestrian. Applied to adults, this ratio is included in the range [1.1;1.4].

These ratios have been applied to the child pedestrian to estimate impact points for the shoulder, the neck and the head.

In order to estimate if the location of the head impact is on the hood or on the windscreen, the distance corresponding to the frontier between the bonnet and the windscreen has been calculated as $BCH + \sqrt{BL^2 + (LEH - BCH)^2} + BONL$. (2) where the parameters are defined in Fig. 3. This value is equal respectively to 165 cm (LV), 198 cm (SUV) and 130 cm (LT) for the three shapes.

3 Results

3.1. Child anthropometry

All the equation coefficients of the linear regressions (1) are given in Table 1. Distances are stated in cm while the weight is in kg. A good determination coefficient (R^2) has to be highlighted for all dimensions. Table 2 gives the main values of the dimensions only for children who are 3, 6, 9, 12 and 15 years old. For each dimension and for each age, the 5th, 50th and 95th percentile values are reported. Because the main injuries encountered concern

the head and the lower limb, the three following heights have to be concerned more particularly: the knee, the iliac crest and the stature. These three heights are relevant because they are associated to the impact with the bumper (knee and/or pelvis) and with the hood or/and windscreen (head).

3.2. Potential impact points on the vehicle

Based on these measurements, it is possible to estimate the different impact points of the child pedestrian body with the car. Fig. 4 shows the location of the bumper impact on the lower limb and the head impact on the bonnet/windscreen of a light vehicle for children aged from 3 to 15 years.

Considering the knee articulation, comparisons with the bumper height of the three vehicle shapes highlight that this segment body is not directly impacted by the bumper car for children under 12 years old. In fact, the lowest bumper height which corresponds to the LV is below the knee height from 12 years old.

About the trochanter height, it is always higher than the bumper height. Indeed, the lowest hip height corresponding to the 5th percentile of a 3 years old child is about 47 cm which is equal to the lowest bumper height corresponding to a LV.

So, age 12 seems to be the limit corresponding to the bumper impact with the lower leg or the upper leg (see Fig. 4). Children under 12 years old are impacted on the upper leg by the bumper. Up to this age, the impact of the child knee with the bumper can be considered as similar to an adult one.

About pelvis height (iliac crest), the age limit to reach the low bonnet of a LV is near to 6 years old. So, under this age, over-risks have to be considered for the pelvis because it is directly impacted by the front end of the car. If we consider now the shape of a LT or SUV, this age limit is close to 15 years. Consequently, LT and SUV seem to be aggressive for child pelvis due to direct impact of the low bonnet independent of the child's age.

Concerning shoulder height, it is observed that it is comprised along the hood, even for LT shape which represents the shortest bonnet of the three shapes. In fact, the shoulder height (age 3) is about 76 cm whereas the lowest bonnet height which corresponds to the LV shape is 74 cm. In the same way, the highest shoulder height (age 15 – 137cm) is close to the 131 cm corresponding to the lowest limit between the hood and the windscreen (LT).

More or less same results have been observed for the neck and chin height since their value are equivalent to shoulder height. Only comparisons concerning LT shape are different because the age limit to reach the windscreen is 12 instead of 14 for the shoulder. But this difference has not to be considered as significant.

Concerning the head, the limit age to hit beyond the hood of a LT vehicle is 8 years old whereas this value is evaluated to more than fourteen years old for LV and SUV. Indeed, mean head height for a 14 year old child is 162 cm against 165 cm for the bonnet limit of a LV. Obviously these comparisons do not take into account the possible sliding effect of the body which imply higher impact of the head. Consequently, if sliding effect is not considered, it can be advanced that child head impact is located essentially on the hood for a LV or a SUV.

4 Discussion

4.1. On the anthropometric results

Concerning the biometric data, if a lot of databases exist on the stature and the weight of children, few ones indicate different segment body heights such as the knee or the pelvis. In particular, no such work has been available in France before this study. It was one of the main reasons for performing this work. Consequently, we were not able to compare our results with other French databases. Nevertheless, it is possible to compare these results with European or

American databases. For example, the Portuguese study on about 1500 children shows a stature comprised between 114.2 and 145.8 with an average value equal to 129.4 (Froufe et al., 2005). This Portuguese sample has taken into consideration children aged between 5 and 14 years old (mean 8 years, SD 1 year). A UK survey has also been conducted by Smith and Norris (2001). A mean stature of about 101cm, 119cm, 137cm and 157cm was observed for respectively 3, 6, 9 and 12 years old children. Comparison with our values tends to show that the stature of the French child is generally comprised between the Portuguese and the English one.

Two identical American studies have been performed. The first one is totally available on internet and was conducted by Snyder in the 1970's on more than 4000 infants and children (Snyder et al., 1977). The second one refers to Tilley's study (2002). Comparison of measurements (see Table 2) shows that from a global point of view, French children are taller than American ones but it has to take into account the date of the surveys more specifically for the Snyder's study.

4.2. On the confrontation children anthropometry / vehicle shape

First of all, our results are in accordance with other studies on this topic. In particular, it appears that the potential impacts highlighted in this study are correlated with accident analysis.

From a general point of view, injuries observed by Roudsari et al. (2005) on child accidents show a large percentage of upper leg and head injuries. If some of them have been attributed to ground fall, main ones have been associated with car impact.

For example, the impact of the pelvis with the low bonnet has been reported by Liu and Yang (2002b) and confirms this type of impact for children under eight years old. On the other hand, no injuries have been observed on the knee in this study. Moreover, Mizuno (2005a)

identified more thigh injuries, such as femur fractures, than adults (in percentage). This result is directly correlated with the present study which highlights the direct contact of the thigh with the bumper.

Concerning the upper extremities, Roudsari et al. (2005) observed 56% upper extremity injuries in about 40 child pedestrian crashes. He mainly assigned the leading sources of injury for this body segment to the ground fall (54%) and hood contact (32%). This is in agreement with the shoulder height because its contact with the car has been associated with the bonnet surface.

About head impact, it has to be noted that we have not taken into account the sliding effect of the body during the impact. If we consider that this effect is the same for children as for adults, it has to multiply the original WAD by a factor comprised between 1.1 and 1.4. In this case, head impact will not be located on the hood but on the windscreen for children above 10, 14 and 7 years old respectively for LV, SUV and LT. Obviously, this remark depends on the trajectory of the child pedestrian during the crash. Indeed, the trajectory of an adult impact by a front end of a LV is usually associated to a wrap trajectory where the pedestrian is carried by the car. In its study, Roudsari et al. (2005) observed in particular this phenomenon for 62% of adult crashes but this percentage decreases to 46% for children. He connects this typical interaction (wrap trajectory) with the relationship between the centre of gravity position of the pedestrian (CG) and the wrap transition point (WTP) on the striking vehicle. WTP is defined as the location on the front of the vehicle where the top hood plane transitions into the front structure and is the pivoting point that the pedestrian is rotated on to the hood (Roudsari et al., 2005). So, if the WTP is below the CG, the body often rotates toward the vehicle, otherwise he is thrown forward or is knocked down. This theory has been considered by a lot of authors in order to reconstruct pedestrian accident (Depriester et al., 2005). In particular, based on a numerical approach, Liu and Yang (2003) finds a greater rotational

motion and consequently higher head impact velocities for the 15 years old child than for the 6 years old. Thus, 15 years old children sustain much severe head impacts in terms of the HIC (Head Injury Criteria).

If we agree that the CG point of the body is located at 55% of the height of the pedestrian (Snyder et al., 1977), our results show that children higher than 133 cm will often be carried by a LV, respectively 190 cm for a SUV or a LT. So, children aged less than 9 years would be often thrown forward or knocked down when they are impacted by a LV. Concerning SUV and LT, it can be considered that children have the same trajectory as adults.

This difference of trajectory for children above 9 years old does not exclude an impact head on the bonnet. In fact, the top surface of the bonnet is the leading cause of head injury as specified in (Mizuno, 2005a).

Concerning regular tests for pedestrian safety, they have been established in order to reduce fatalities of pedestrian accidents (Mizuno, 2005a). The aim of these experimental tests is to encourage car manufacturers to design vehicle shape safer for pedestrians. They are now submitted to consider the aggressiveness of the car during an impact against a pedestrian. These countermeasures consist of 4 sub-system tests. These tests procedures represent respectively the leg impact with the bumper, the pelvis impact with the low bonnet, the child head on the hood and the adult head on the hood or windscreen (UE, 2003). Concerning the test procedure about the child head impact on the hood, it considers a head-form representing the head of a six years old child because it has been identified that the age group around 6 years old has the highest frequency of pedestrian accidents. The head impact test areas on the vehicle, defined on the basis of the WAD, correspond to the areas that accident data show as the most commonly struck by the head of a child pedestrian (Mizuno, 2005a). The chosen WAD values to perform these tests are between 100 cm and 170 cm. Compared to our own curves, this range includes all children aged from 3 to 15 years. Thus, this comparison

confirms that the test procedure takes into account all child pedestrians because it covers all of the child anthropometry.

5. Conclusion

The aim of this work was to confront child anthropometry with vehicle shape in order to identify potential impact points on the front end car during a pedestrian accident. It allowed in particular the highlighting of a direct impact of the thigh with the bumper for children aged above 12 years. This result underlines over-risks for this segment body. Above this age, it is the knee which is directly impact by the bumper like adults.

Concerning the head, it appears to be in contact with the hood of vehicle types LV or SUV for every age. This confirms the pertinence of a test procedure on the head impact on the bonnet in order to design vehicle shapes safer for all child pedestrians.

Height of the centre of gravity has also been discussed and showed that children aged less than 9 years tend to be thrown forward or knocked down instead of having a wrap trajectory.

Concerning the child anthropometry, this study gives some information on the evolution of the child height for several segment bodies. They can be used to conceive physical or numerical models representative of a child. In particular, they can be useful to design a pedestrian dummy or to generate a finite element model such as (Mizuno et al., 2005b).

These data can be also used in the anthropology field in order to evaluate child growth or in legal medicine to estimate age from measurements.

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Fig. 1. Sample distribution by age group

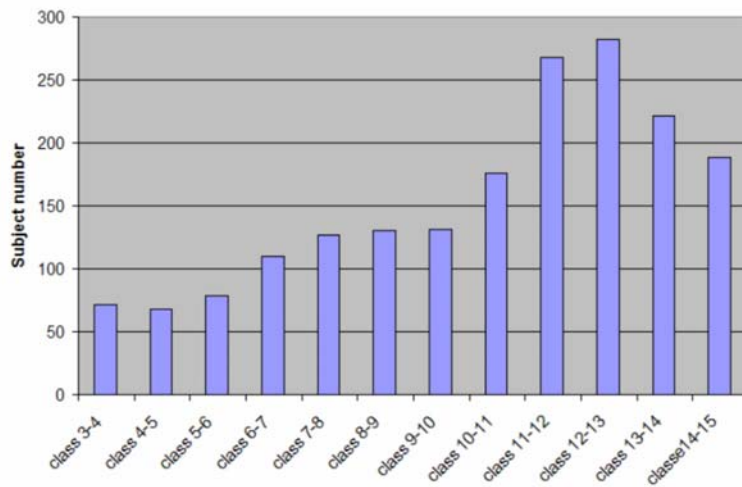


Fig. 2. List of measurements and example photo.

1 : Stature; 2: Chin height; 3: Shoulder height; 4: Trochanter height; 5: Knee height; 6: Iliac crest height; 7: Neck height.

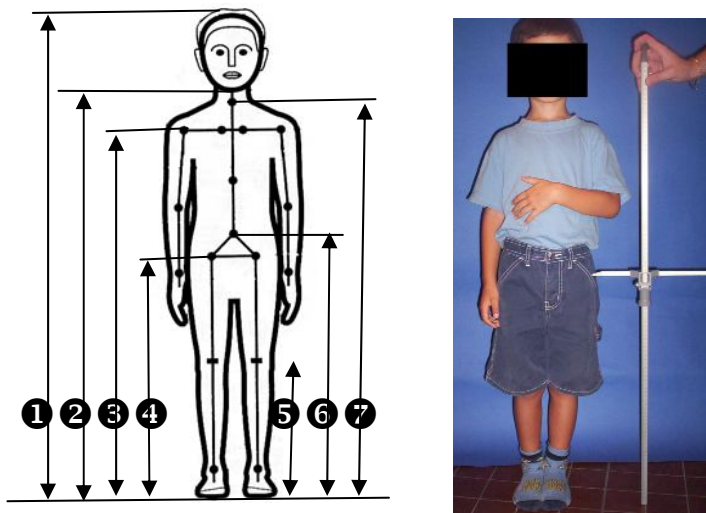


Fig. 3. Definition of car front shape from (Mizuno, 2005a)

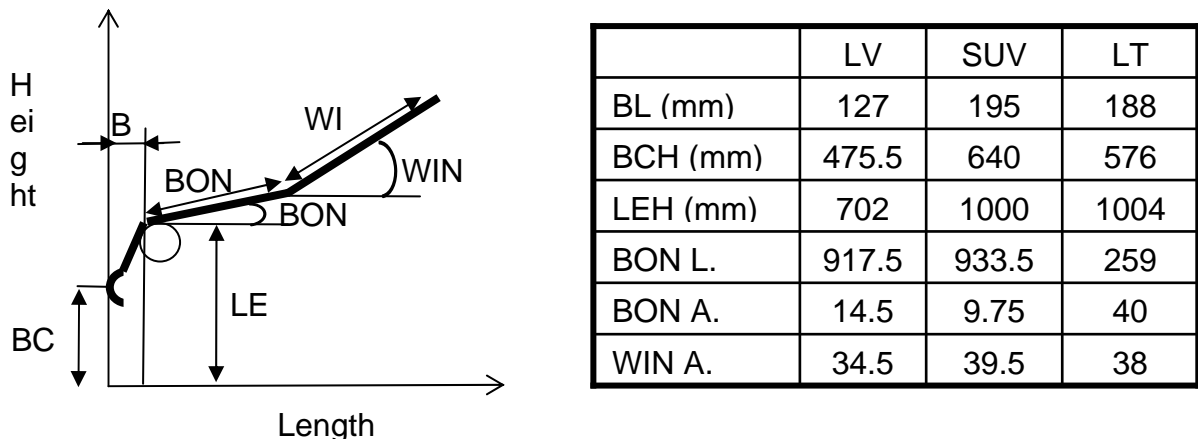


Fig. 4. Location of the bumper impact on the lower limb and of the head impact on the bonnet/windscreen for a passenger vehicle.

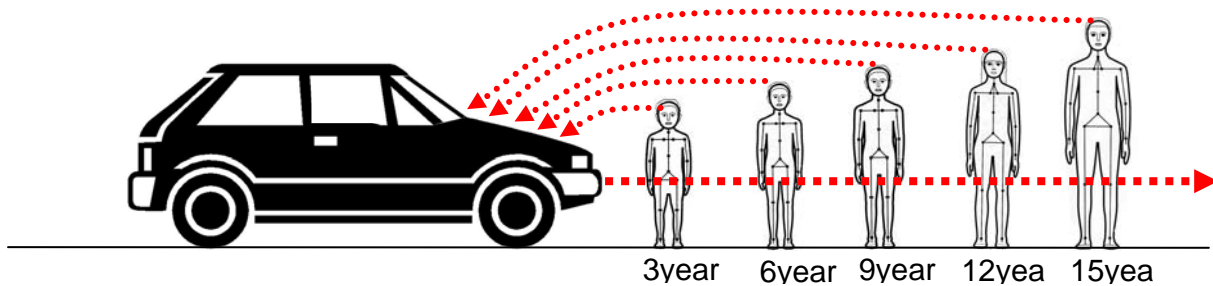


Table 1. Coefficients of the linear regression equations ($y=a*x+b$) for each measurement (y) function of age expressed in years ($3 \leq x \leq 15$) and the corresponding r-squared (R^2).

Measurement	Slope (a)	Intercept (b)	r-squared (R^2)
1 – Stature (cm)	5.82	80.95	0.79
2 – Chin height (cm)	5.52	63.19	0.89
3 – Shoulder height (cm)	5.30	60.04	0.81
4 – Trochanter height (cm)	3.34	37.20	0.81
5 – Knee height (cm)	1.86	21.16	0.68
6 – Iliac crest height (cm)	3.95	44.26	0.86
7 – Neck Height (cm)	5.38	63.97	0.80
8 – Weight (kg)	3.85	-1.54	0.67

Table 2. 5th, 50th and 95th percentiles values for each dimension and each age compared to the US studies.

Measurement	Serre (France, 2010)			Snyder (USA, 1977)	Tilley (USA, 2002)
	5th	50th	95th	50th	50th
1 – Stature (cm)					
3 y. o.	90.5	98.3	105.9	93.2	93.4
6 y. o.	111.3	120.0	129.7	113.6	114.5
9 y. o.	127.2	136.6	147.2	129.9	132.6
12 y. o.	143.5	154.6	166.7	146.5	148.6
15 y. o.	154.2	166.8	178.4	-	163.6
2 – Chin height (cm)					
3 y. o.	71.0	79.5	86.7	-	-
6 y. o.	91.8	99.8	108.2	-	-
9 y. o.	106.8	115.1	124.6	-	-
12 y. o.	121.5	132.3	144.7	-	-
15 y. o.	134.3	143.6	155.0	-	-
3 – Shoulder height (cm)					
3 y. o.	69.3	76.6	82.1	-	72.0
6 y. o.	87.6	95.2	104.3	-	90.0
9 y. o.	102.3	110.6	119.7	-	106.4
12 y. o.	116.8	126.8	138.7	-	116.2
15 y. o.	127.4	136.9	149.0	-	128.0
4 – Trochanter height (cm)					
3 y. o.	38.4	44.4	50.4	37.3	43.9
6 y. o.	52.9	59.3	67.4	50.8	57.6
9 y. o.	63.6	69.7	77.4	61.2	68.9
12 y. o.	72.0	79.5	87.8	70.8	79.8
15 y. o.	79.7	85.2	93.8	-	86.6
5 – Knee height (cm)					
3 y. o.	21.2	25.1	30.3	-	24.4
6 y. o.	29.7	33.2	38.4	-	31.9
9 y. o.	35.4	39.6	43.2	-	37.9
12 y. o.	38.8	44.5	50.1	-	43.9
15 y. o.	42.1	47.4	53.2	-	47.0
6 - Iliac crest height (cm)					
3 y. o.	47.1	54.4	60.6	-	-
6 y. o.	64.4	70.3	77.6	-	-
9 y. o.	74.7	82.1	90.2	-	-
12 y. o.	85.2	93.9	104.5	-	-
15 y. o.	94.2	102.1	110.0	-	-
7 – Neck Height (cm)					
3 y. o.	72.5	79.5	86.5	-	-
6 y. o.	91.3	100.1	108.4	-	-
9 y. o.	107.0	114.9	124.9	-	-
12 y. o.	121.4	131.8	145.2	-	-
15 y. o.	133.2	143.3	154.6	-	-
8 – Weight (kg)					
3 y. o.	12.6	16.0	19.9	13.2	14.0
6 y. o.	19.0	23.7	31.8	20.1	20.0
9 y. o.	25.0	31.9	43.5	26.9	28.6
12 y. o.	33.2	45.5	63.0	37.3	39.1
15 y. o.	46.4	56.0	72.6	-	54.2