COMPARISON BETWEEN NEW DATA ON CHILDREN ANTHROPOMETRY AND CRS DIMENSIONS

Thierry, Serre
Sebastien, Thouvenin
Christian, Brunet
Laboratoire de Biomécanique Appliquée – UMRT24, INRETS/University of Méditerranée,
Marseille, France
Loic Lalys
CNRS UPR 2147,
Paris, France
Christophe, Bartoli
Georges, Leonetti
UMR 6578, CNRS/University of Méditerranée
Marseille, France

Paper 09-0484

ABSTRACT

The objective of this paper is to compare the morphology of children aged from 3 to 15 years old with actual Child Restraint System dimensions.
First, an anthropometry study has been performed on about 2000 French children aged from 3 to 15 years old. For each subject, 15 external measurements have been acquired in particular in sitting position. They include classical dimensions like weight and heights (head-seat, shoulder-seat, etc) but also new data concerning for example the sternum length, the xyphoid angle or the thorax and abdominal widths.
In a second step, 13 dimensions have been measured on about 30 actual CRS. These CRS concern only forward facing system such as booster seat and they represent the different standard groups: 0+,1, 2, 3. To complete the geometry acquisition, 6 dimensions concerning the back seat of 6 different vehicles have been measured. Dimensions have been focused in particular on the belt position in the car or in the CRS.
For each child anthropometric dimension, the 5th, 25th, 50th, 75th and 95th percentiles curves are given and discussed. Then, these dimensions are compared with the measurements performed on the CRS and on the vehicles. In particular, data concerning the belt position regarding the children morphology along ages are detailed. The location of the belt on the shoulder is more specifically evaluated.
Results highlight that some of the CRS appear as unsuitable regarding the children anthropometry. This article shows for example a gap between the CRS classification based on children weight.

INTRODUCTION

Road transport safety, particularly for children, has become a priority for all government. Indeed, statistical analysis in the field of accidentology and epidemiology show that the proportion of killed children on the road needs to encourage researches on this field (OECD, 2004). For example, in France, the ratio of children killed in road accidents is about 4% and even if this percentage is not excessive, it can not be acceptable (ONISR, 2006). Children are mainly involved in pedestrians and bicyclist accidents but the mostly killed children have been observed as car passengers (OECD, 2004, ONISR, 2006; CHILD, 2006).
In order to reduce this fatality, the most important measure to protect child occupants of vehicles is the provision and use of efficiency child safety restraint system (CRS).
Concerning this last point, a lot of researches has been performed these last years in order to evaluate performance of the CRS (NCAPS, 2006; EEVC, 2003). Nevertheless it appears important gaps in this field. The first major problem concerns in particular the large range of child sizes and the child anatomical structure. The second is the incorrect use of restraints, either because the restraint is inappropriate for the age of the child, is badly fitted, or incorrectly used.
Systems such as ISOFIX or Latch have improved the efficiency of CRS by integrating seating systems to the vehicle (OECD, 2004). But some problems still stayed on the adaptability of these systems to the children morphology.
In parallel restraint standards have been defined in order to propose categories of CRS (ISO/TR13214; Bell, 1997). But this classification is mainly based on the child's weight and it appears incoherence between the regulation which imposes to have a CRS for every child with a height lower than 150cm while the selection of the CRS is based on the weight or the age. Previous studies have shown that this classification is not well appropriate to child

anthropometry (Griffith King, 1969; Durbin, 2003; Huang, 2006; Anderson, 2007). However, these studies are based on old anthropometric databases such as (Snyder, 1977), incomplete one or are focused on only few geometrical parameters such as only the weight or the seat cushion length regarding the buttock-knee length.
The objective of this paper is to evaluate the adaptability of CRS by having a general approach which includes all anthropometric characteristics of the children in sitting posture. It consists on acquiring new data on the morphology of children aged from 3 to 15 years old in sitting position and to compare them with several actual Child Restraint System dimensions.

ANTHROPOMETRICAL DATA

Material and method

French healthy children aged from 3 to 15 years old have been measured in order to acquire new anthropometrical information. Subjects come mainly from the south of France (suburb of Marseille). Measurements have been performed in paediatric services of Marseille hospitals and in different schools. Children have been measured with the agreement of their parents, themselves and a paediatric doctor or school headmaster. Data anonymity has been respected.
The sample is made up of about 2000 children. This sample is decomposed in range groups of one year. Each group includes minimum 60 children with a sex ratio at least 30 boys and 30 girls.
Because it was important to have geometrical information in seating posture, some measurements have been performed in this position. The subject sat erect on a flat horizontal surface with the head held in order to have the Franckfurt plane horizontal.

The acquisition protocol was based on the same one classically used for adults in the field of biometry. Only the somatology has been considered and 15 dimensions have been acquired (see figure 1):

1. weight
2. stature (in standing position)
3. sitting height
4. acromion-seat height
5. knee-ground height
6. buttock-sole length (leg shoot out)
7. thigh length
8. abdominal depth
9. thorax depth
10. abdominal width
11. thorax width
12. bi-trochanter width
13. bi-acromial width
14. sternum length
15. xyphoid angle

Classical anthropological instruments have been used: anthropometer, sliding caliper, spreading caliper with rounded ends, tape measure (accuracy 1mm), goniometer and scales (accuracy 100gr).

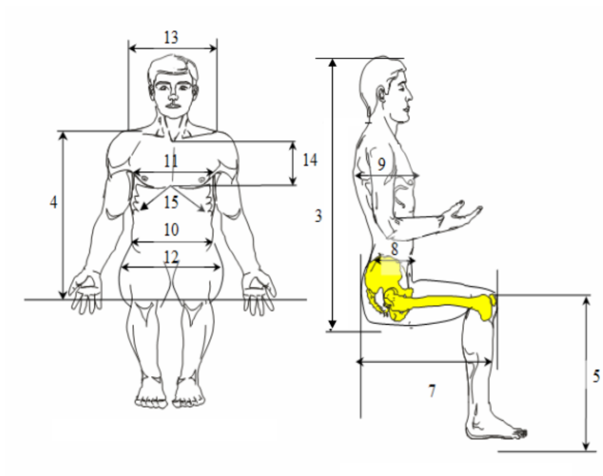


Figure 1. Anthropometric measurements

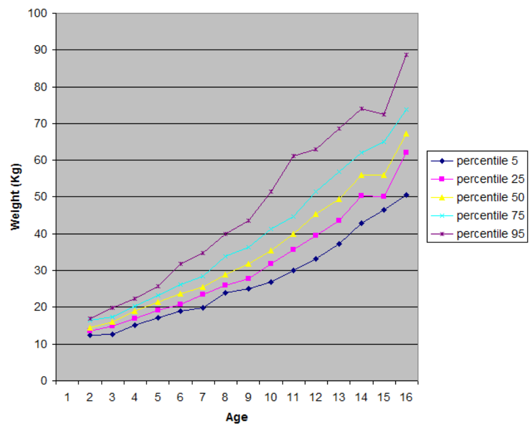
Finally, the acquisition date and the date of birth of the child are noted in order to calculate exactly his age when the measurements were taken

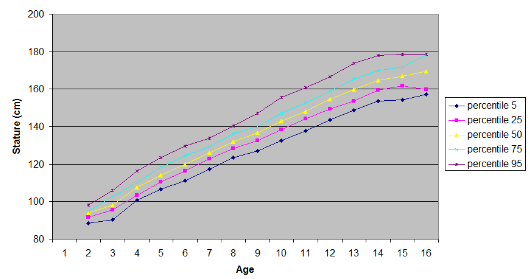
It is important to highlight the fact that in particular the sternum length or the xyphoïd angle were acquired in order to provide new information which can not be found in literature (Biard, 1997). These measurements have been taken in order to compare them with the belt position.

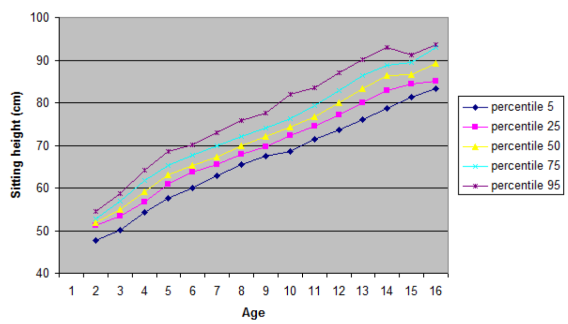
Results

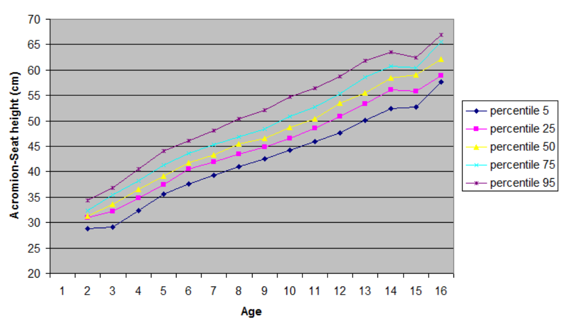
For each dimension and each age, a classical statistical analysis was performed. It concerns the computation of the 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentile values using the Microsoft Excel software.

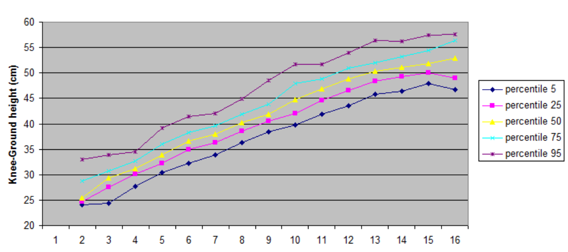
The following figure 2 gives the corresponding curves for the respective measured dimensions in function of age (in year). All dimensions are given in cm except the xyphoid angle which is given in degrees and the weight in Kg.

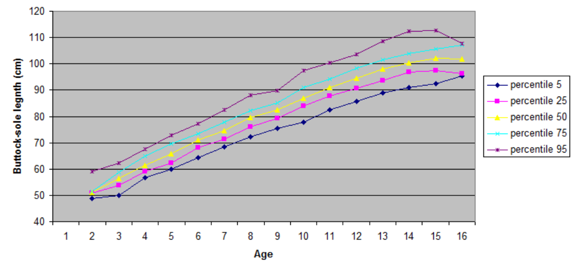

Weight (Kg)
100 90 80 70 60 50 40 30 20 10 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

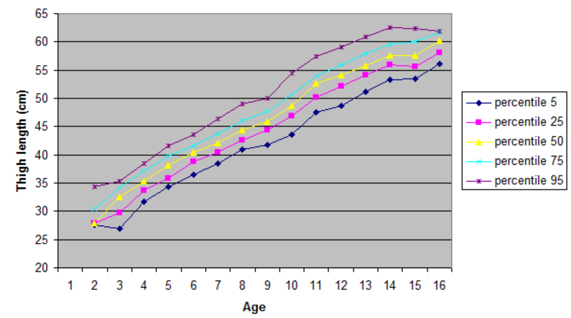

Stature (cm)
200 180 160 140 120 100 80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

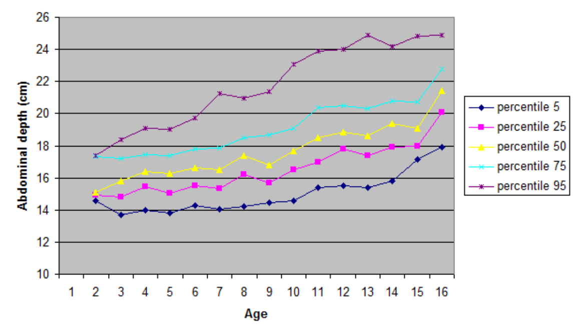

Sitting height (cm)
100 90 80 70 60 50 40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

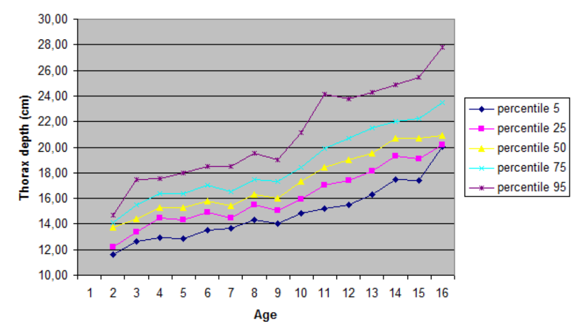

Acromion-Seat height (cm)
70 65 60 55 50 45 40 35 30 25 20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

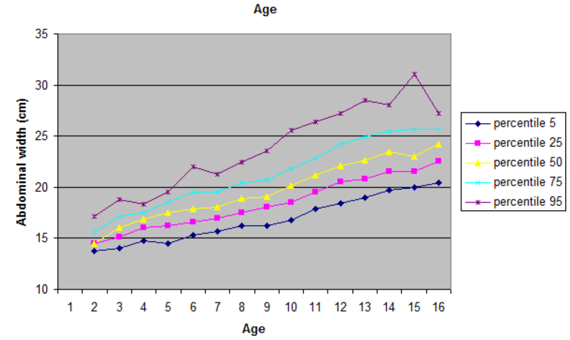

Knee-Ground height (cm)
60 55 50 45 40 35 30 25 20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Buttock-sole legnth (cm)
120 110 100 90 80 70 60 50 40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Thigh length (cm)
65 60 55 50 45 40 35 30 25 20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Abdominal depth (cm)
26 24 22 20 18 16 14 12 10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Thorax depth (cm)
30,00 28,00 26,00 24,00 22,00 20,00 18,00 16,00 14,00 12,00 10,00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95


Abdominal width (cm)
35 30 25 20 15 10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age
percentile 5
percentile 25
percentile 50
percentile 75
percentile 95

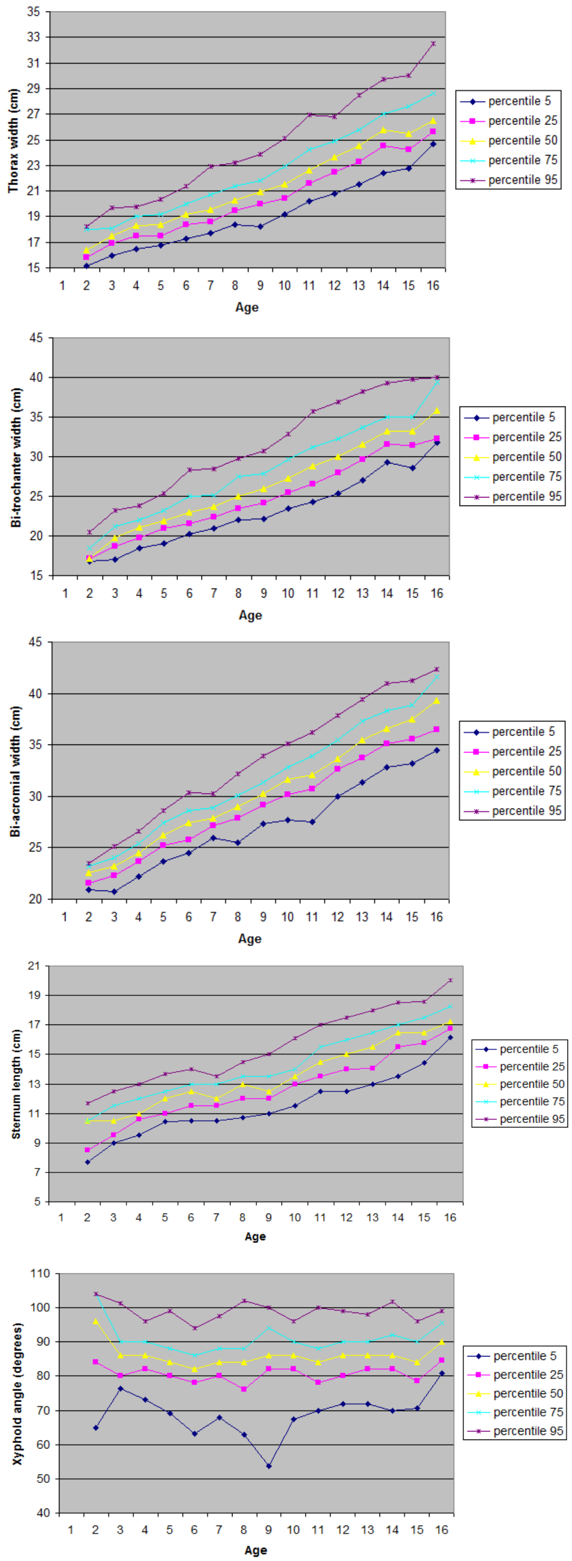


Figure 2: Curves of the 5th, 25th, 50th, 75th and 95th percentile values for each dimension and each age

Discussion

From a global point of view, curves show a constant growth of all parameters except few ones. In particular, the weight corridor increases in function of the age. This particularity can be attributed and tend to show obesity signs for the children population. Abdominal dimensions such as the width or the depth follow the same tendency and can be linked also to the obesity.
Concerning specifically the xyphoid angle, no specific increasing can be observed. This means that this parameter stays constant during the child growth.

Concerning the same database identified in bibliography, if a lot of them exist on the stature and the weight of children, few indicate dimensions by body segment. Moreover, main databases describing precisely and completely the children anthropometry are based on US population (Weber, 1985; Dreyfuss, 2002, Pheasant, 2001) and are sometimes dated (Snyder, 1977). Others concern European population but none describe the anthropometry of French children. For example, a UK survey was conducted by Smith and Norris in 2001 (Smith, 2001). Two identical American studies have also 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, 1977). The second one referred to (Dreyfuss, 2002). A comparison between our results with these European or American databases has been performed in a previous work (Serre, 2006). From a global point of view, values provided by these authors are 12% lower than ours.
This previous study was also focused on the 3 and 6 years old children data in order to compare these data with the corresponding dummies (HybridIII-3 HybridIII-6, P3 and P6). Comparisons with child dummies show that the difference is negligible because it is close to 3% (Serre, 2006).

CRS AND VEHICLE MEASUREMENTS

Child Restraint System data

In order to compare the children morphology with actual restraint system, measurements have been performed on several commercialised child seat and booster. These CRS concern only forward facing system such as booster seat and they represent the different standard groups: 0+, 1, 2, 3. Thirteen dimensions have been measured on 28 actual CRS.
The corresponding recorded data are the following ones (see figure 3):

1. the standard group of the system regarding the ECE R44 classification
2. the total seat cushion depth
3. the seat cushion depth from the anchorage point
4. the seat cushion width
5. the seat cushion height
6. the seat height
7. the maximal height of the belt position
8. the minimal height of the belt position
9. the headrest height
10. the backrest depth
11. the abdominal belt height (at the anchorage point)
12. the maximal lateral distance for the thigh
13. the maximal height for the thigh

Figure 3: CRS dimensions

Table 1 summarises all the measured dimensions. All the values are given in centimetres and a “0” value signifies that this parameter is not applicable for the system.

Table 1.
CRS measurements

Restraint system	Standard Group (regarding ECE R44)	Seat cushion depth	Seat cushion depth (from the ancohrage point)	seat cushion width	seat cushion height	Seat height	Maximal heigth of the belt guide	Minimal heigth of the belt guide	Headrest heigth	Backrest depth	Abdominal belt height	Maximal lateral distance for the thigh	Maximal height for thigh
1	1	32	17	27	22	55	0	0	37	10	0	16	10
2	1	32	15	26	22	36	0	0	37	10	0	17	13
3	1	28	14	26	30	54	0	0	27	10	0	13	10
4	1	28	13	30	23	55	0	0	0	23	0	13	11
5	1	32	17	27	22	57	0	0	40	10	0	14	10
6	2-3	35	0	26	10	0	0	0	0	0	10	0	0
7	3	33	0	25	11	62	45		42	8	11	0	0
8	2-3	37	17	27	12	65	23	0	0	5	12	14	14
9	2-3	37	17	26	12	64	24	0	0	6	12	14	15
10	1-2-3	37	22	26	12	72	18	0	49	5	12	14	
11	0+	34	16	27	20	53	0	0	0	8	0	17	15
12	0+	33	11	27	21	53	0	0	36	10	0	14	14
13	2-3	36	19	25	11	65	26	0	42	8	11	15	14
14	0+	38	19	29	24	45	0	0	0	4	0	14	12
15	2-3	34	0	27	10	62	38	0	0	7	13	0	0
16	3	27	0	26	12	59	36	0	36	4	11	0	0
17	2-3	31	0	27	13	59	35	0	38	3	11	0	0
18	2-3	39	0	33	17	59	50	37	72	5	10	0	0
19	2-3	34	0	28	11	74	49	31	52	8	11	0	0
20	2-3	34	0	26	14	78	55	36	55	7	12	0	0
21	1-2-3	33	15	28	15	61	41	32	41	5	14	21	13
22	2-3	33	0	25	15	76	57	40	57	12	12	0	0
23	1-2-3	33	11	21	14	66	55	0	36	5	16	12	14
24	1-2-3	30	10	30	22	64	50	0	40	5	0	9	13
25	2-3	35	0	25	12	70	46	38	46	8	12	0	0
26	1	29	15	29	18	56	0	0	0	10	0	14	11
27	2-3	27	0	31	23	58	35	0	34	12	23	0	0
28	1	28	17	30	19	35	0	0	0	10	0	15	13

Vehicle measurements

In order to complete the geometrical characterization of the sitting position of the children, some measurements have been taken on family cars. Dimensions concern only the rear seat of the vehicle and the corresponding belt position. These measurements allow to evaluate the adequacy of the booster+vehicle’s belt coupling and the transition when the child will not use any more CRS. Six dimensions have been performed on six different vehicles. Three lengths concern the rear seat while the six others concern the seatbelt position.

The performed measurements on the vehicle are listed below (see figure 4):

1. the seat height (backrest)
2. the seat width
3. the bench seat depth (which corresponds to the seat cushion length as defined by (Huang, 2006)
4. the maximal height of the seatbelt anchorage point which correspond to the shoulder belt
5. the minimal height of the seatbelt anchorage point (when an adjustment is available on the vehicle)
6. the lateral distance between the two anchorage points of the abdominal seatbelt (from the buckle to the lateral edge of the bench seat).

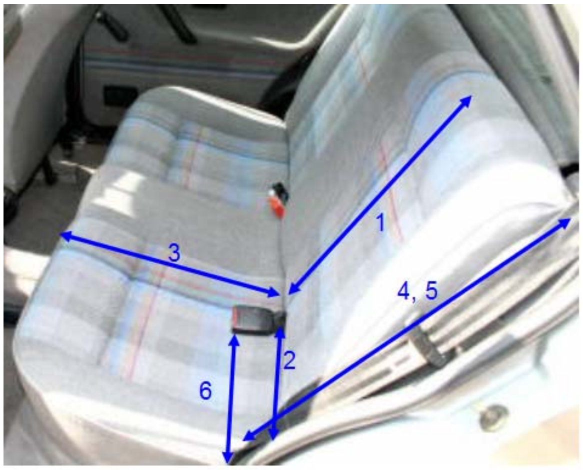


Figure 4: Vehicle dimensions

Table 2 gives all the measured dimensions. Values are given in centimetres and a "0" value signifies that this parameter is not applicable for the vehicle (only concern the availability of a seatbelt height adjustment).

Table 2.
Vehicle measurements

Vehicle ID	Seat height	Seat width	Seat depth	maximal heigth of the seatbelt	minimal heigth of the seat belt	lateral distance between anchorage points
1	59	49	46	70	0	41
2	57	59	44	72	61	41
3	60	59	44	58	0	49
4	61	44	48	69	0	42
5	67	65	44	70	0	48
6	58	50	47	59	0	29

COMPARISON OF THE DATA

Evaluation of the seatbelt position

Previously to compare the amount of anthropometric data with CRS's dimensions, it appears necessary to estimate the seatbelt position regarding child's trunk. So, the objective of this first work is to evaluate in particular the position of the webbing against the clavicle or the sternum. Indeed, it is accepted that the good position of the seatbelt is on the middle of the clavicle and on the sternum (Chabert, 1996).
To do this work, considering the following scheme which represents the child trunk and the seatbelt position (see figure 5).

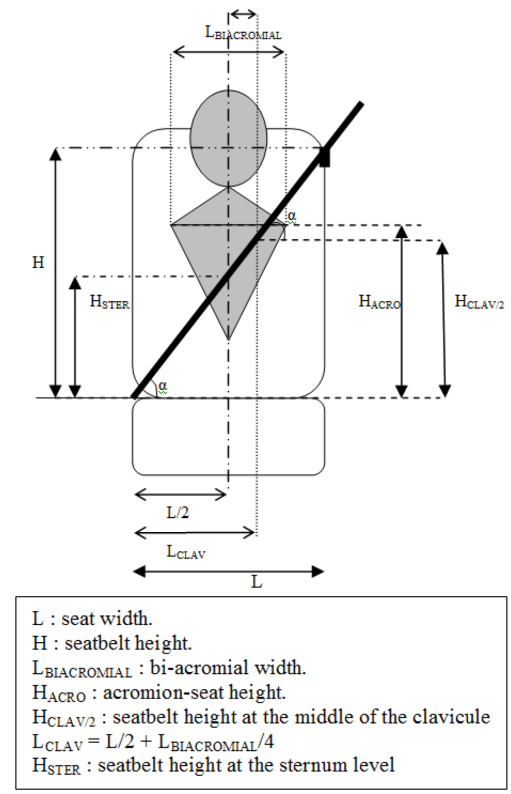


Figure 5: Computation of the seatbelt position regarding child's trunk

The middle of the clavicle is so estimated at the quarter of the bi-acromial distance from the sagittal plane. With this assumption, the height of the vehicle seatbelt at the level of the middle of the clavicle can be calculated by:

$$H_{CLAV/2}=H/L*L_{CLAV} \qquad (1)$$

Concerning the sternum, the height of the seatbelt at the level of the sternum can be calculated by:

$$H_{STER}=H/L*L/2 \qquad (2)$$

Of course, these equations are mainly valid when only the seatbelt of the vehicle is used i.e. when no CRS is present or when a booster is installed. In this last case, the booster cushion height has to be added to the acromion height. Finally, if a child seat is considered, these calculations have to be adapted to the configuration.

Comparison of the seatbelt position

Regarding the amount of recorded data, a lot of comparisons can be done. So, we have decided to focus the exploitation on few characteristics.

<u>Clavicle height versus vehicle seatbelt without CRS</u> – This comparison concern the real clavicle height of the children in sitting position (considered as the acromion height) and the seatbelt height of the vehicle at the clavicle level (such as calculated using equation 1) without CRS. Figure 6 superimposed the 5th, 25th, 50th, 75th and 95th percentile values of the acromion height for all children (curves in black) and the corresponding seatbelt height for each vehicle (other coloured curves).

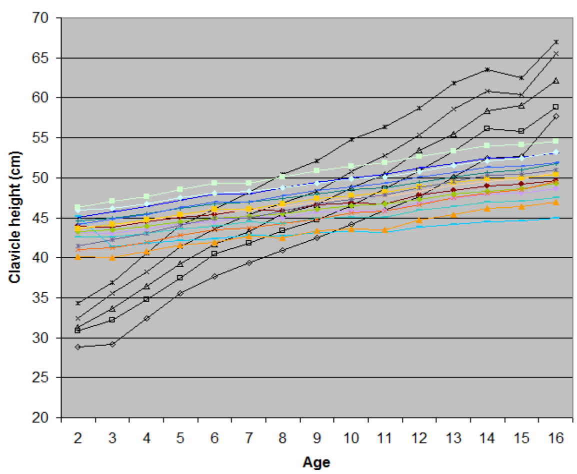


Figure 6: Comparison of the real clavicle height of the children in sitting position (black curves) with the seatbelt height of all vehicles at the clavicle level (coloured curves).

These curves shows that until age of 7, children can not used only the vehicle seatbelt. From 7 years old, 50% children can avoid the CRS to consider only the seatbelt of the vehicle. In fact, this limit corresponds to the minimal clavicle height (i.e. acromion height) needed to reach the minimal height of the seatbelt vehicle at the clavicle level. After this limit the real clavicle height of the children is higher than the seatbelt vehicle height at the clavicle level and this last one fitted and followed the shoulder height growth.

<u>Clavicle height versus vehicle seatbelt with CRS</u> – This comparison is the same as above but it is considered that the children are sited in a CRS. The height of the CRS cushion is so added to the acromion height of the children. In this case, all the black curves of the figure 6 go up from 10 cm (CRS n° 6) to 30 cm (CRS n°33). So it is easy to notice that all children older then 3 are correctly protected by the coupling CRS+seatbelt vehicle.

Comparison of the CRS's cushion width with the bi-trochanter dimension.

The objective of this comparison is to evaluate if the dimension of the CRS's cushion is adequate with the children morphology at the pelvis level. Figure 7 compares, for all ages, the bi-trochanter distance measured on the children sample with the seat cushion width measured on all CRS.

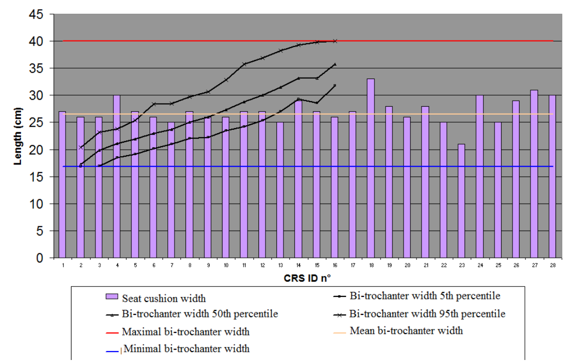


Figure 7: Comparison of the bi-trochanter width (curves) with the seat cushion width measured on all CRS (bar chart).

This comparison shows that all CRS (except n°23) are enough large to be used until 9 years old. Regarding the morphology of the children pelvis, this parameter does not appear as a limit for the use of the CRS.

Comparison of the children weight and the standard classification.

The objective of this comparison is to evaluate the adequacy of the standard classification of the CRS based on the children weight. The standard classes have been defined by the ECE R44 (Bell, 1997) as follow:

- group 1: from 9 to 18kg, age lower than 3,5 y.o.
- group 2: from 15 to 25 kg, age from 3 top 7 y.o.
- group 3: from 22 to 36 kg, age from 6 to 12 y.o.

These data have been reported on the following figure 8 and superimposed with the weight growth of the sample.

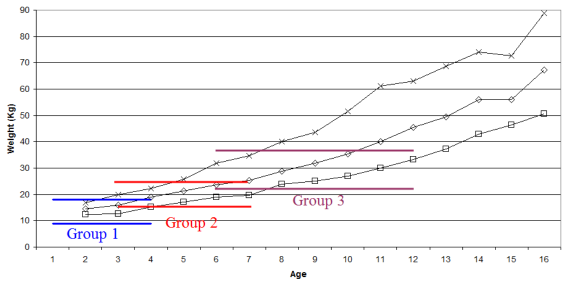


Figure 8: Comparison of the children weight (black curves of the 5th, 50th and 95th percentiles) with the standard classification

Due to obesity signs previously discussed and observed, this figure highlights that for children aged between 5 and 6, the standard classification is inadequate. Indeed, for children aged around 6, about 50% of them have a restraint unsuited to their weight. This incoherence of the classification confirms the results obtained by Anderson in 2006 and tends to show that the standard classification has to be improved.

CONCLUSION

This research allows to acquire new anthropometric data on the children morphology aged from 3 to 16 years old. Acquisition of complementary data on CRS geometry and cars allows also to have a first evaluation of the adequacy of CRS regarding the children anthropometry. Results highlight some discrepancies in particular concerning the standard classification of the CRS.
Nevertheless, these results have to be considered as a preliminary study. Indeed, a small part of the geometrical database has been exploited to compare children anthropometry with CRS dimensions. More work could be performed like verifying the seatbelt position on the children thorax (sternum length or xyphoid angle). In the same way, geometrical data on lower limb have not been analysed too. It could be useful to investigate the distance between the rear seat and the front one.
Finally, it could be valuable to work on a revision of the standard classification in order to base it on other parameter than the weight.

ACKNOWLEDGEMENT

Authors would like to thank all the people involved in the anthropometry survey: children, parents, school staff (Ecole La Présentation - Salon de Provence, Ecole Viala Lacoste – Salon de Provence, Cours St Thomas d'Aquin - Marseille, Collège M. Wajsfelner - Cuffies) and staff from Marseille hospitals (Pr Allessandrini, Pr Jouve, Pr Magalon). Special thanks to staff from INRETS and from the Anthropology and Forensic department for their valuable contribution to this study.

REFERENCES

Anderson RWG, Hutchinson TP, 2007, "The feasibility of aged-based criteria for child restraint selection" ESV conference, paper 07-02220

Bell R, Burleigh D., 1997, "An empirical comparison of the FMVSS213 and ECE 44.03 Standards for Child Restraints", Proceedings of the 2nd symposium on child occupant protection, SAE paper 973312.

Biard R., Alonzo F., Muge A.C., Serindat S., 1997, « Amélioration des mannequins-enfants européens pour les essais dynamiques d'homologation. » Rapport INRETS n° 215

Chabert L., Ghannouchi S., Cavallero C., Bonnoit J., 1996, « Anatomical study and three-dimensional reconstruction of the belted human body in seated position », ESV Conference, paper n° 96-S10-O-04

CHILD, 2006, European project "Child Injury Led Design",http://www.lboro.ac.uk/research/esri/vehicle-road-safety/projects/child%20web%20site/index2.htm

Dreyfuss H., Tilley A.R., 2002, The measure of man & woman, edited by John Wiley & Sons, New York.

Durbin D.R., Runge J., 2003, "Booster Seats for Children: Closing the Gap Between Science and Public Policy in the United States" ; Traffic injuries prevention ; 4:5–8.

EEVC, 2003, Child Safety EEVC WG18. http://www.eevc.org/wgpages/wg18/wg18index.htm

Griffith King B, Paul E.C., Spitznagel C.R., 1969, "Children's automobile safety restraints: characteristics and body measurements", SAE paper 690467.

Huang S., Reed M. 2006. "Comparison of child body dimensions with rear seat geometry", SAE no 2006-01-1142.

ISO/TR13214, "Road vehicles – Child restraint system – compilation of safety regulation and standards"

NCAPS, 2006, http://www.erso.eu

OECD, 2004, “Keeping children safe in traffic”, OECD Observer, May 2004, http://www.oecd.org

ONISR, 2006, “Grands thèmes de la sécurité routière en France », La documentation Française.

Pheasant S., 2001. “Bodyspace”, Taylor & Francis Inc. Philadephia, USA.

Serre T., Lalys L., Bartoli C., Chritia-Lotter A., Leonetti G., Brunet C., 2006, « 3 and 6 years old child anthropometry and comparison with crash dummies.” SAE Paper n° 2006-01-2354

Smith, S., Norris, B, 2001, “Childata: Assessment of the Validity of Data.”, http://www.virart.nott.ac.uk/pstg/childchanges.htm.

Snyder R.G., Schneider L.W., Owings C.L., Reynolds H.M., Golomb D.H., Schork M.A., 1977, “Anthropometry of infants, children and youths to age 18 for product safety design.” Report no UM-HSRI-77-17, Consumer Product Safety Commission, Bethesda, MD

Weber K., Lehman R.J., Schneider L.W., 1985, Child anthropometry for restraint system design. Technical report UMTRI 85-23