A Pilot Study of Three-Dimensional Child Anthropometry for Vehicle Safety Analysis

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The publicly available anthropometric data for U.S. children were published in 1977, lack body shape data, and do not include measurements in supported sitting postures that are needed for vehicle safety applications. A pilot study was conducted of methods using standard anthropometry, laser scanning, and three-dimensional coordinate measurement to develop the data needed to improve the sizes and shapes of crash dummies and other design tools used to develop and assess child restraints, belt-positioning boosters, and vehicle seat and belt restraint systems. A total of 15 children ages 4 to 11 were measured in this pilot study.

INTRODUCTION

The design of child restraints and crash dummies used to assess protection for children in vehicles is guided by anthropometric data gathered in the 1970s. Snyder et al. (1977), from the University of Michigan Transportation Research Institute (UMTRI), obtained standard anthropometric dimensions (lengths, widths, circumferences) on 4127 children from ages 2 weeks to 18 years. A compilation of these data by Weber et al. (1985) has been widely used to size crash dummies (e.g., Mertz et al. 2001) and child restraints.

The large sample size and rigorous methodology have maintained the relevance of this dataset, but several limitations are becoming increasingly important. First, overall population anthropometry in the U.S. has changed, with increased body weight for children at all ages. Increased body weight would be be associated with large circumference dimensions. Second, the 1977 UMTRI study did not explicitly sample children with Hispanic ethnicity, who represent the fastest-growing race/ethnicity group in the U.S.

Third, the 1977 UMTRI study was conducted before the development of fast, efficient methods for recording three-dimensional body shape, and consequently only standard, manual measurements are available. The lack of information on body shape hinders the application of the data to protective equipment that fits close to the body, including child restraints for use in vehicles.

Sampling for the 1977 study was guided by data from the National Health and Nutrition Examination Survey, a long-running public health monitoring program (NCHS, 2012). NHANES now releases data in two-year blocks that can be combined for various analyses. The current NHANES data include stature and body weight for U.S. children, along with demographic information including gender, race, and ethnicity. The availability of this information means that it is not necessary for a study focused on detailed anthropometry to sample representatively. Instead, the results of a study can be reweighted using NHANES, or more generally interpreted in the context of this large-scale dataset.

At least two previous anthropometric studies in Europe have included 3D scanning. The 3DChild study in France measured children ages 0 to 5 years old for clothing and furniture design. The SizeGermany study also sampled children. However, neither of these studies included the supported seated postures that are typical of children in automobiles.

Another important development in anthropometry has been the implementation of multivariate statistical methods for modeling body shape, in particular the ability to predict body shape based on overall body dimensions (Allen et al. 2003). The current work is based on methods previously applied to adult scan data (Reed and Parkinson 2008). These methods allow statistics from the NHANES study to be used to identify, for example, the mean stature and body weight for children of a particular age. Those values can then be used to predict seated posture and body shape using data of the sort gathered in this pilot study.

Additionally, methods for measuring automotive seated postures with children have been developed and applied to quantify the effects of vehicle seat variables and child body size (Reed et al. 2005; Reed et al. 2006; Reed et al. 2008). These methods describe posture as the configuration of surface landmarks on the body, along with a kinematic linkage developed by estimating internal joint locations from the surface landmarks (Reed et al. 1999).

This paper describes a pilot for a new UMTRI study to develop a database of three-dimensional body shape for children ages 4 to 12 using laser scanning and three-dimensional coordinate measurement. Unlike previous U.S. studies of adults, the current study includes measurements of supported seated postures relevant to the vehicle environment. A total of 15 children were measured in the pilot study.

METHODS

Laser Scanners

Figure 1 shows the VITUS XXL (Human Solutions, LLC) whole-body laser scanner used in the study. Laser heads in four towers illuminate a horizontal line on the subject. Images recorded from cameras above and below each laser are processed to obtain coordinate data. The system is accurate to within approximately 2 mm, depending on the type of measurement required and the location within the measurement volume. The system records a grayscale image from each camera along with three-dimensional coordinate data describing the scanned surface.

Custom fixtures were fabricated to support seated postures. As shown in Figure 1, vertical poles supported the child's hands so that the arms were abducted and flexed, providing good access to the torso for the scanner. The rigid seat could be set to flat and 14.5 degrees to horizontal, and two thin, pivoting back supports could be adjusted to achieve a range of recline angles. Seat height was adjusted by raising and lowering the platform under the feet.

Figure 1. Child in the VITUS XXL whole-body laser scanner, showing fixtures used to support seated postures.

In some postures, body regions of interest that were shadowed from the whole-body scanner were measured using a handheld laser scanning head mounted to a FARO Arm coordinate measurement system.

Hardseat

The locations of body landmarks were measured using a FARO Arm coordinate digitizer while the children sat in a specially designed laboratory *hardseat* that provides access to posterior landmarks on the spine and pelvis. The landmark set and measurement methods were derived from those used in previous studies of automotive posture for both adults and children (Reed et al. 1999, Reed et al. 2005, Reed et al. 2006). Figure 2 shows a child being measured in the hardseat.

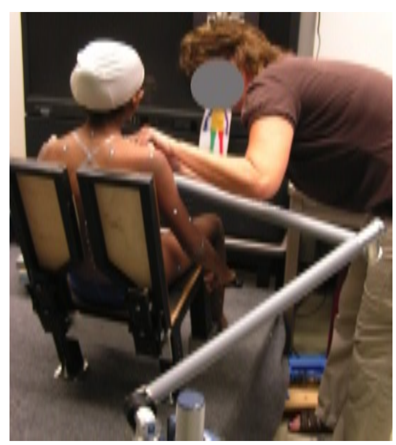

Figure 2. Laboratory hardseat.

Standard Anthropometry

Standard anthropometric dimensions, including stature, body weight, and erect sitting height, were recorded. Procedures were generally identical to those used in ANSUR (Gordon et al. 1989) and functionally equivalent to those used in the 1977 UMTRI study. Table 1 lists the 23 dimensions obtained for each subject. Figure 3 illustrates measurement of seated acromion height.

Table 1
Standard Anthropometric Dimensions

Weight	Buttock Knee Length
Stature	Buttock-Popliteal Length
Erect Sitting Height	Biacromial Breadth
Eye Height (Sitting)	Shoulder Breadth
Acromial Height (Sitting)	Chest Depth (on a scapula)
Knee Height	Chest Depth (on spine)
Tragion to Top of Head	Bispinous (BiASIS) Breadth
Head Length	Chest Circumference at Axilla
Head Breadth	Waist Circumference
Shoulder Elbow Length	Hip Circumference at Buttocks
Elbow-Hand Length	Upper Thigh Circumference
Maximum Hip Breadth	

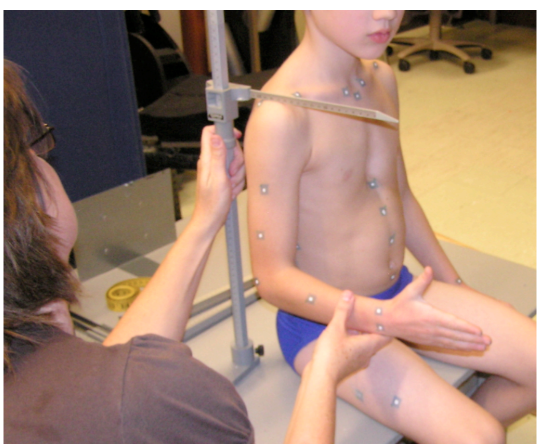

Figure 3. Measuring seated acromion height.

Vehicle Seat Measurements

Child posture and belt fit were measured while sitting on a vehicle second-row bench seat with and without a backless belt-positioning booster. The seat back angle was set to 23 degrees (SAE A40) and the seat cushion angle was set to 14.5 degrees (SAE A27). The seat height was 270 mm (SAE H30). In each condition, 27 landmarks defining skeletal posture and belt fit were recorded using the FARO Arm. The methods were identical to those used in Reed et al. (2008). Figure 4 shows a child in the two vehicle-seat conditions.

Figure 4. Vehicle seat conditions with (left) and without (right) a belt-positioning booster.

Scan Postures

Each child was scanned in 4 standing and 17 seated postures chosen to span those typical of second-row seating in vehicles. The postures included both unsupported and supported sitting. Table 2 lists the postures.

Table 2
Scan Postures

Posture	Purpose and Description
Recline1 Recline2 Recline3 Recline4	A series of postures in which the subject goes from a very erect posture to a very slumped posture, while keeping the knee angle constant. The seat is set with a 23˚ back angle and 14.5˚ cushion angle. The seatback moves rearward to increase the slump. The hips stay forward on the seat so that the bottoms of the thighs and backs of the calves are scanned well. Seat surface should not cut into the back of the thighs. The arms are forward so that the sides of the torso scan well – but the shoulders are still in a resting position (as if arms were hanging by the side of the subject). Elbows and shoulders are relaxed with the subject's hands on the handles supporting the weight of the arm.
SittingLap	An erect posture on a level seat in which the tops of the thighs are visible in the full body scanner
SittingISO	A posture compatible with ISO 20685
Booster	A posture very similar to that of a child in a booster seat. The fore-aft distance between the tragion and ASIS of the subject in this posture are set using the values collected on the subject while sitting on the booster in the vehicle seat (Grand Am buck). The backs of the calves should not be touching the front of the booster seat.
HalfSeat	A posture in which half of the subject's body is fully scanned – including the back and under the buttocks

ArmFlex90 Arm FlexMax ArmAbd90 ArmAbdMax ArmExtMax	A series of arm positions used to get surfaces of the shoulder, neck and torso
SpineFlexMin SpineFlexMax SpineFlexMed	A series of postures in which the back goes from natural sitting to as much like the letter "C" as possible. In SpineMax the chin is on the chest.
SpineExtMax	Entire spine – neck to lower back arched as much as possible.
StandingNatrl	Natural, yet symmetrical, standing posture to get a good scan of arms hanging at sides
StandingArmAb	Similar to StandingNatrl but with arms away from body to get a good scan of torso
StandingErect	Similar to StandingArmAb but with spine erect
StandingTpose	T-pose and legs wide used to get under arm and between leg surfaces

Protocol

Written informed consent was obtained from the caregivers of each child and oral assent was obtained from each child. The child changed into scanwear, consisting of close-fitting swimsuits. Body landmarks were marked on the skin using a pattern of water-soluble, non-toxic body paint that was chosen to produce targets that are readily viewed in the scan output regardless of skin tone. Standard anthropometry was obtained from the child, followed by measurement in the hardseat and the vehicle seat. All testing was completed in a single session lasting approximately two hours.

Scan Data Processing

The surface data obtained from the laser scanners were processed through a pipeline including several steps.

1. Props and artifacts (for example, handholds) were removed manually in the ScanWorX software (Human Solutions, GmbH).
2. Hand-scan data were aligned and merged with the whole-body scan data where needed using Geomagic Studio software (Geomagic.com).
3. Optical landmark locations were manually recorded using a custom script in the Meshlab software (meshlab.org).

PILOT STUDY RESULTS

Standard Anthropometry

Table 3 lists the standard dimensions for the participants in the pilot study.

Table 3
Standard Anthropometry: Selected Dimensions

Dimension	Min	Mean	Max
Stature (mm)	1007	1243	1450
Weight (kg)	14.4	24.8	37.4
Erect Sitting Height (mm)	560	661	735
Age (yr)	4	8	11

Body Scans

Figure 5 shows body scans from one subject in some of the sampled postures. The data have been processed to remove props and to fill holes. The illustrations were made using surface models decimated to 50k polygons from approximately 400k in the original data.

DISCUSSION

This pilot study developed methods for obtaining detailed body shape and posture data for children in a wide range of postures, including postures similar to automotive seated postures.. A larger study of 150 children now underway will provide the first useful sample of data on the body shapes of US children in seated and standing postures. The study methodology takes advantage of the availability of large-sample data on overall body size (stature and body weight) for US children from the ongoing NHANES studies. With these data, a statistical model of posture and body shape based on a diverse sample of children can be used to make predictions for the population as a whole.

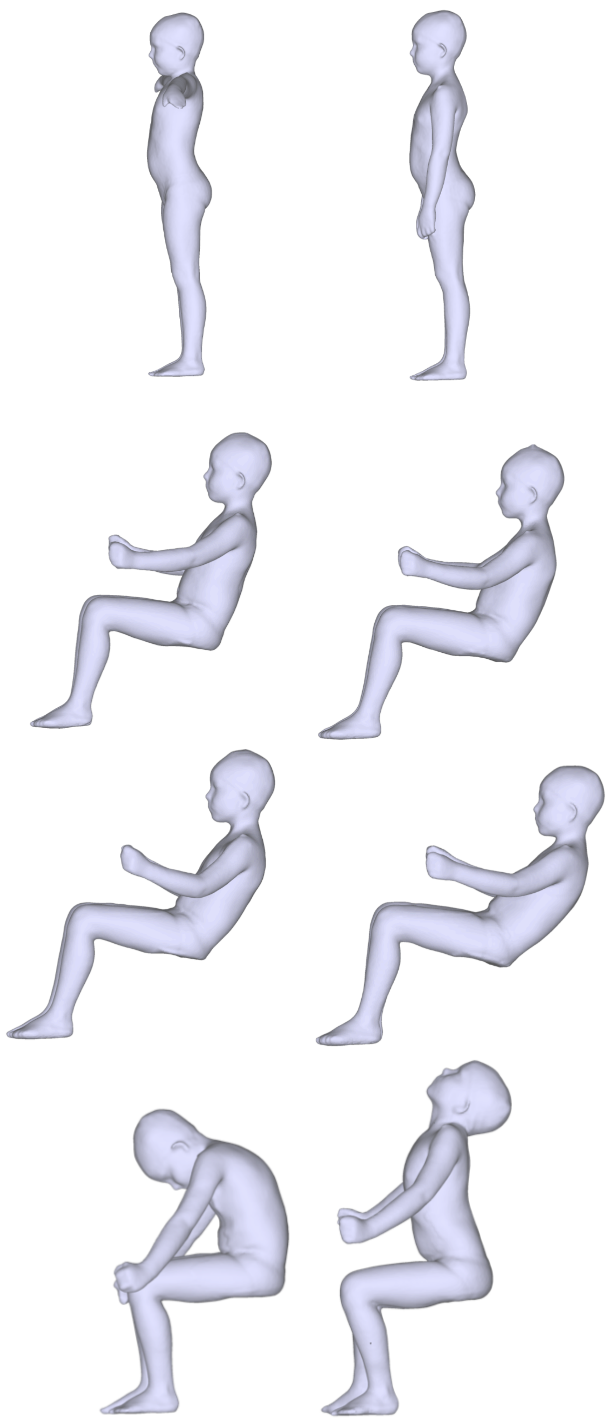

Figure 5. Body scans in 8 of the sampled postures for one subject.

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