Teenage Activities and Postures when Passengers in a Vehicle Environment

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Teenage Activities and Postures when Passengers in a Vehicle Environment

Chantal S. Parenteau, Christopher Andrecovich, Sarah Sherman, Mats Svensson

Abstract An observational investigation was first conducted to identify the common activities of teenage occupants in a vehicle environment. These included playing or texting on a cell phone, grabbing objects in a schoolbag positioned in the footwell, applying make-up while looking in the visor mirror (female), texting with legs crossed (male), looking down at an object, reaching for objects, and changing the radio. These activities were simulated in a static user study. The back of the head-to-head restraint anterior surface was 2.1 ± 2.7 cm for male volunteers and 3.5 ± 2.2 cm for female volunteers while normally seated. In comparison to when normally seated, the head moved 8.0 ± 3.8 cm and 4.3 ± 2.8 cm respectively when the volunteers were interacting with a cell phone. The back of the head-to-head restraint anterior surface was 59.4 ± 5.9 cm for the male volunteers and 55.8 ± 5.1 cm for the female volunteers when grabbing a book in the footwell area. The results were, however, similar (65.7% ±.8.0% v 65.9% ±.6.4%) when normalized by seated height. The head rotated 27.2 ± 14.7 deg in males and 19.1 ± 8.9 deg by females when playing a game on the cell phone. The results of this study highlight the increase in head-to-head restraint and head rotation during common activities conducted by teenagers when riding in the front-seat.

Keywords Teenager, posture, passenger, out-of-position, observations.

I. INTRODUCTION

Restraint systems, such as seatbelts, airbags and/or seats, are designed for occupants sitting in an upright and forward-facing position. Variability in occupant seating position and posture may affect the protective performance of the vehicle restraint systems. For example, Carlsson [1] found that an increase in head-to-head restraint distance was associated with higher risks for whiplash injury (cervical strain, AIS 1) in rear-end crashes. Similar findings were reported by Jakobsson et al. [2].

Occupant seating posture has been documented in the literature in both laboratory and driving environments. In the last two decades, focus was placed on the driver position relative to the steering wheel and instrument panel due to concerns with respect to airbag interactions. Occupant kinematics were also assessed during braking [3-6] and other pre-crash activities [7].

In a braking scenario, the occupant can move forward decreasing the distance between the occupant and the instrument panel or steering wheel and increasing the head-to-head restraint distance [8]. Carlsson and Davidson [9] reported a forward displacement of 5.5 ± 2.6 cm for the chest and 9.7 ± 4.7 cm for the head with braking. The authors noted larger forward displacement with taller volunteers and with females compared to males with a similar seated height.

Ghaffari et al. [10] investigated lap-shoulder belted male driver kinematics in automated lane change and in lane change with braking scenarios with and without pretensioner activation. For the automated lane change condition, the maximum lateral T1 excursion was reduced from 13 cm to 6.6 cm with pre-pretensioner activation. In lane change with braking scenarios, the T1 excursion was reduced by 6.8 cm (13.5 cm v. 6.7 cm) in the lateral axis and by 2.4 cm (6.5 cm v. 4.1 cm) in the horizontal axis.

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Bohman et al. [11] and Baker et al. [12] studied children kinematics when lap-shoulder belted in a booster seat or when seated in the second-row seat during various steering scenarios. The upper torso was observed to slide out of the shoulder belt. The amount of sliding was influenced by anthropometry, initial occupant seating position and seat belt routing.

Most studies were conducted with occupants originally sitting in an upright and forward-facing position. In recent years, observational studies have been performed to document occupant initial position and posture in driving conditions with second-row adults [13,14,32] and children [15]. For example, Reed et al. [32] evaluated the postures and associated prevalence of front-seat passenger in a naturalistic study. The authors reported that sideway head rotation was frequent. Arbogast et al. [15] conducted a naturalistic observational study on children riding with family members. The authors noted a large variability in head positions, in particular for those restrained in booster seats or in vehicle seats compared to children restrained in a forward-facing child seat with a five-point restraint. They reported that activities such as interacting with electronic devices played a significant role in head position.

In the recent years, the safety community has focused on integrating crash avoidance and occupant safety technologies. For example, the PRE-SAFE system currently available in some Mercedes vehicles can activate a motorized pre-pretensioner in some pre-crash scenarios to remove belt slack and help improve occupant seating position and posture. Shoeneburg et al. [16] reported a 42% (82 mm to 47 mm) reduction in forward chest displacement with activation of the motorized pre-pretensioner.

According to Loup Ventures [17], about 100 million fully automated (Level 5) vehicles will be on the road by 2040. Morgan, Stanley [18] reported a 100% penetration of autonomous vehicles in late 2020s. In high and full automation vehicles (Level 4-5), occupants will no longer need to drive and may all become passengers. As a result, a new focus is being placed on documenting passenger seating positions. New seating configurations and adjustments will be desired for these autonomous environments. Various seat concepts have been proposed, such as seats that move the driver away from the steering wheel and/or that rotate such as swivel seats [19-23]. Research is being conducted on the effect of reclining the seatback on the occupant seating position [14]. Safety concerns for being out-of-position will be highlighted. The current study focused on identifying common teenage passenger seating postures since this segment of the population has yet to be evaluated. Furthermore, the current teenage population will become the future occupants of fully autonomous vehicles when they become fully automated (Level-5). It is thus important to better understand and document how they sit and interact as passengers of current vehicles.

The objective of the first part of the study was to observe and identify teenage passenger activities in a dynamic driving environment using various camera. In a second part of the study, postures were quantified using teenage volunteers seated in selected activities.

II. METHODS

Part 1 - Observational investigation to identify teenage activities

Participants: Four teenage volunteers, 16 to 17 years old, were used. One male volunteer was observed twice, once seated in the right-front and once seated in the right-rear passenger seat. The three female volunteers were seated in the right-front, right-rear, and left-rear passenger seats. Prior to the commencement of this observational investigation, signed permission was obtained from the parents and the volunteers were asked for permission to use video. Appendix A provides additional information on the test setup.

Part 2 - User study

Participants: Ten female and ten male teenage volunteers, 15 to 19 years old, were used in this study. No special selection criteria were used. The volunteers were placed in the right-front seat and were asked to put on the lap-shoulder belt. The volunteers were recruited from two different high schools. Appendix B provides additional information on the test setup. Table B1 summarizes the anthropometric data collected for each volunteer. For the female volunteers, the mean stature without shoes was 1.67 ± 0.09.m with a range of 1.52 to 1.83 m. It was 1.81 ± 0.05 m with a range of 1.75 to 1.91 m for the male volunteers. The mean seated height was 84.6 ± 3.6 cm for the female and 90.6 ± 4.1 cm for the male volunteers. The corresponding weight was 63.7 ± 16.8 kg and 76.5 ± 6.7 kg, respectively.

Testing Protocol: The study protocol was approved by an Institutional Review Board for human-subject research at Exponent. After giving written informed consent by both the teenagers and their parents/guardians, the volunteers changed into the testing clothes. Female volunteers were asked to wear a tank top and pants and male volunteers were asked to wear only shorts for ease of locating bony landmarks. All volunteers wore a swim cap.

Procedure: The volunteers were not given any instructions about being tensed or relaxed in order to reproduce normal passenger postures while seated in the right front seat. The volunteers were asked to perform the following activities:

1. Sitting "normally" or baseline
2. Playing a game on a cell phone to simulate texting
3. Grabbing a book from a bag in the footwell
4. Applying make-up while looking in the visor mirror (female)/ texting with legs crossed (males)
5. Sorting cards, simulating looking at and interacting with an object
6. Reading a book

Targets were placed on the swim cap, left shoulder, head restraint, seatback and D-ring. An inch tape was placed on the right shoulder, arm, and torso belt webbing. Two GoPro cameras were used to capture the occupant kinematics; one was on the driver window and one on the right-front dash.

Various measurements were analyzed by post-processing of the videos. Appendix B provides additional information of the measured data and analysis, including the following selected measurements:

- Back of head-to-anterior head restraint (HR): Gap between posterior head and head restraint along the longitudinal axis.
- Normalized back of head-to-anterior HR: Back of head-to-anterior HR divided by seated height.
- Head target rotation: Head target rotation relative to baseline (angle at activity 1).
- Acromion target-to-seatback target distance (horizontal, vertical, and resultant)
- Extracted seat belt webbing length using a measuring tape.

III. RESULTS

Part 1 - Observational investigation to identify teenage activities

In the first part of the study, seven activities were identified while observing various teenagers in a vehicle environment. These included sitting "normally" (baseline, referred to as activity 1), texting (activity 2), grabbing objects from schoolbag in footwell area (activity 3), conducting beauty related tasks (activity 4), looking down at an object (activity 5), reaching for objects (activity 6) and changing the radio (activity 7). Figure 1 shows examples of the activities. Appendix A provides additional information.

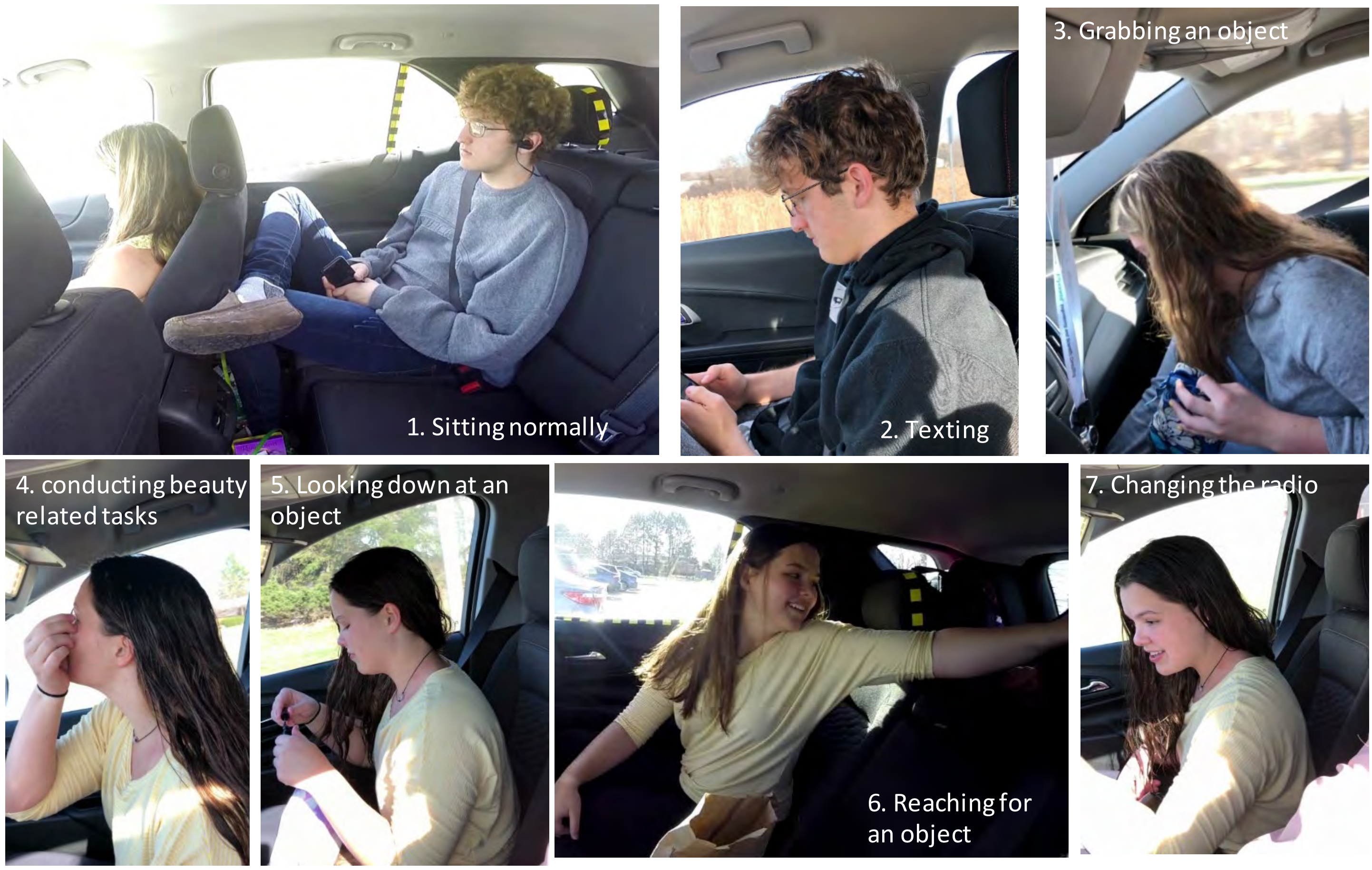

Fig 1. Teenager activities observed in a vehicle environment.

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Part 2 – User study

Six activities were identified from the observational investigation. These activities were simulated by the following actions in the user study: 1. Sitting "normally" or baseline, 2. Playing a game on a cell phone, 3. Grabbing a book in bag placed on the footwell, 4. Pretending to apply make-up using a brush while looking in the visor mirror (female) or texting with legs crossed (males), 5. Sorting cards and 6. Reading a book. It should be noted that sorting cards was not an activity identified during the observational investigation. The activity 5 (Figure 1) was "Looking down at an object". This activity was simulated by sorting cards in an attempt to focus the volunteer's attention to the object.

Figure 2 shows a male volunteer seated in the right-front passenger seat while conducting the various activities and Figure 3, a female volunteer. Measurements were taken to document and quantify the passenger's posture while conducting the activities

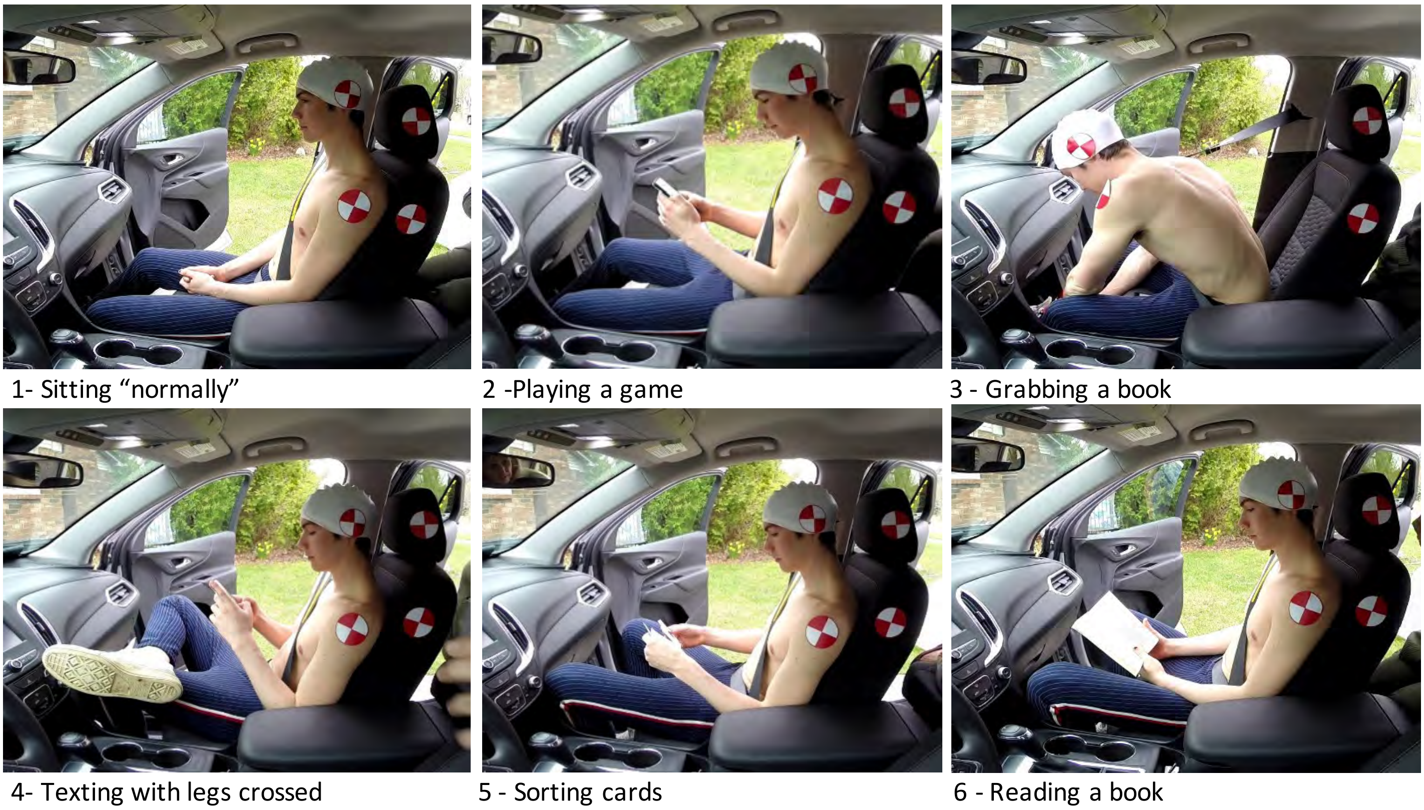


Fig 2. Right-front seat seating postures with male volunteer #3.

Fig. 3: Right-front seat seating postures with female volunteer #4.

Appendix B tabulates the video analysis data by volunteer number and activities. Table B2 summarizes the head target horizontal distance (x-axis), vertical distance (z-axis), two-dimensional resultant with respect to the target on the head restraint for the six postures. Table B3 summarizes the acromion target horizontal distance (x-axis), vertical distance (z-axis), two-dimensional resultant with respect to the target on the seatback for the six activities.

Back of the head-to-anterior surface of head restraint (HR): The distances shown in Table B2 are representative of head-to-head restraint target. Table B4 provides information on the volunteer's initial head position with respect to the head restraint. This includes the horizontal distance from the back of the head to the head restraint, the back of the head to the center of the head target and vertical distance from the top of the head to the top of the head restraint.

To assess the clearance between the back of the head to the anterior surface of the head restraint, the initial distances between the back of the head to the anterior surface of the head restraint (summarized in B4) was subtracted from the horizontal distance between the head and head restraint targets. Table B5 shows the difference, identified as Delta X. The Delta X was then subtracted from the head target to head restraint target in the horizontal axis for each volunteer and activity (see Table B4). Table B5 shows the results. Table 1 summarizes the average and standard deviation data. The average distance from the back of the head-to-head restraint along the longitudinal axis was 2.1 ± 2.7 cm for male volunteers and 3.5 ± 2.2 cm for female volunteers in activity 1. The corresponding distance was 10.5 ± 3.6 cm and 8.0 ± 3.9 cm in activity 2 (playing a game) and 10.0 ± 3.2 cm and 16.4 cm ± 10.1 cm in activity 5 (sorting cards).

To minimize the effect of height, each calculated back of head to anterior head restraint measurement was normalized by the seated height for each occupant. Table B5 shows the normalized responses. The average and standard deviation for each activity are shown in Table 1. On average, the normalized distance between the back of the head to the anterior surface of the head restraint was similar for both male and female volunteers, at 65.7% ±.8.0% and 65.9% ±.6.4% for activity 3. The normalized distance was 2.5-times greater in females than in males in activity 4 but the activities were different between the two groups.

TABLE 1
Measurement data by activity and gender.

		Volunteer measurements											
		Male		**Female**		**Male**		**Female**		**Male**		**Female**	
		Ave	sd	Ave	sd	Ave	sd	Ave	sd	Ave	sd	Ave	sd
Activities	#	**Back of Head-to-Anterior HR (cm)**				**Normalized Back of Head-to-Anterior HR (%)**				**Head rotation (deg)**			
Sitting normally	1	2.1	2.7	3.5	2.2	2.3	2.9	4.1	2.6	0.0	0.0	0.0	0.0
Playing game	2	10.5	3.6	8.0	3.9	11.5	3.7	9.3	4.3	27.2	14.7	19.1	8.9
Grabbing object/book in footwell	3	59.4	5.9	55.8	5.1	65.7	8.0	65.9	6.4	65.3	14.5	55.1	16.9
Texting w/ legs crossed (M)/	4	9.9	4.4	21.8	6.2	10.8	4.6	25.6	6.7	22.7	11.3	-11.0	12.6
Sorting cards	5	10.0	3.2	16.4	10.1	11.0	3.5	19.4	12.0	25.8	9.1	25.3	13.7
Reading a book	6	9.6	3.5	11.8	10.2	10.5	3.7	13.8	11.7	21.9	14.4	19.7	13.2
		Seated Height (cm)											
		90.6	4.1	84.6	3.6								

M: Males, F: Females

Table B4 also summarizes the back of head-to-head target and top of the head to top of head restraint in the baseline activity 1 (sitting "normally"). The average distance from the center of the head target to the back of the volunteers' head was 7.8 ± 1.7 cm for male volunteers and 7.0 ± 1.0 cm for female volunteers. The top of the head to top of head restraint was -3.8 cm for volunteer 4; the negative value indicated that head was below the restraint, consistent with the images in Figure 3.

The greatest change in posture was noted to be during activity 3 (grabbing a book from a bag in the footwell). To further illustrate this change, the average head location coordinates in activity 1 (baseline) were compared to the head coordinates in activity 3 for the male and female volunteers. Figure 4 shows the results. The head moved about 57.3 cm along the horizontal axis and -17.9 cm along the vertical axis in male volunteers. For female volunteers, the head moved 52.3 cm and -12.5 cm, respectively. The negative value means that the head moved downwards.

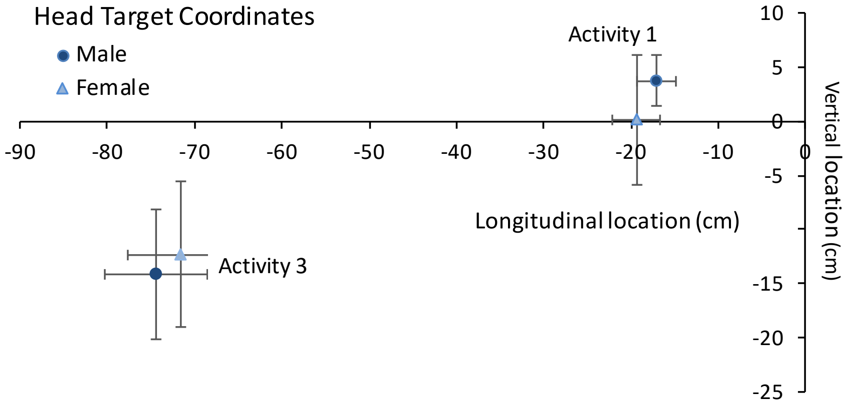
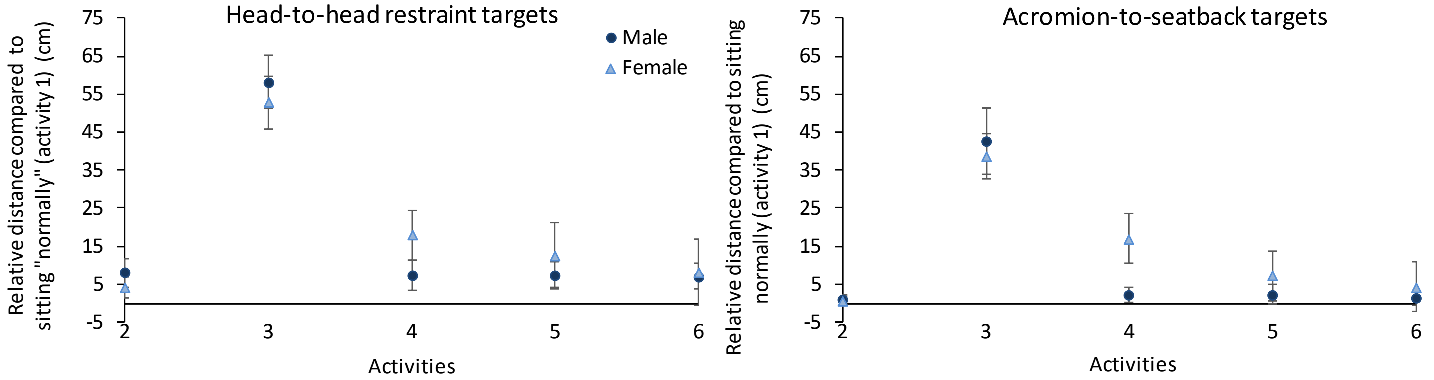


Fig 4. Activity 1 (sitting normally) and activity 3 (grabbing book in footwell) head target location obtained from video analysis.

Measurement relative to activity 1: To assess the relative change in distance due to changes in activities, the measurements taken at baseline (activity 1) were subtracted for the measurements taken at activity 2 to 6 for each volunteer. Appendix B6 summarizes the results including average, standard deviation, minimum and maximum data. Figure 5 shows the head and acromion displacement results. The head-to-head restraint was 58.3 ± 7.0 cm greater in activity 3 than in activity 1 in the male group and 52.8 ± 7.0 cm the female group. The acromion measurements in activity 3 increased by 42.7 ± 8.8 cm in male volunteers and 38.7 ± 5.9 cm in female volunteers when compared to baseline.



2. Playing a game on a cell phone
3. Grabbing book in bag in the footwell
4. Applying make-up while looking in the visor mirror (females)/ texting with legs crossed (males)
5. Sorting cards, simulating looking at an object
6. Reading a book, simulating looking at an object

Fig 5. Resultant head and acromion measurements from video analysis.

Head rotation: Similarly, the relative head absolute angle was calculated for activity 2 to 6 by subtracting the baseline head angle measured during activity 1 (see Appendix B for additional information). The average and standard deviation are provided in Table 1. The absolute head angle during activity 4 was 22.7 deg ± 11.3 deg for the males and -11.0 deg ± 12.6 deg for the females. The positive value represents a forward head rotation (looking down). The differences in the results seen can be explained by the difference in tasks. For activity 4, the male volunteers were asked to sit with their legs crossed while texting and the female volunteers were asked to simulate applying make-up. The male volunteers moved their head down to look at their cell phones (Figure 2) while the female volunteers lifted their head up to look in the sun visor mirror (Figure 3). The lifting of the head was dependent on the seated height.

Tape measurements: Appendix B7 summarizes the data collected using a tape measure for each volunteer. The head-to-head restraint and acromion to seatback distances obtained with the tape measure were generally larger than the ones obtained with the video analysis. For example, the average head-to-head restraint target measurement in activity 3 was 13.4 cm larger for males with a measuring tape than with the video analysis. It was 15.5 cm larger for females. The video analysis data were determined in a 2-dimensional plane and thus seems more accurate of relative distances.

Tape measurements: Head-to-head restraint distance, acromion-to-seatback distance and extracted webbing length were also assessed with a tape measure for each activity with each volunteer. The extracted webbing length was not collected for 2 volunteers in the baseline activity 1. The extracted webbing length represents the distance for the outboard anchor point to the D-ring. This measurement was also used to determine the relative increase in webbing length due to changes in posture. To do so, the measurements taken at baseline activity 1 were subtracted for the measurements taken at activity 2 to 6 for each volunteer.

Figure 6 shows the average change in webbing length between activity 1 and the other activities. The results indicate that webbing seemed to decrease in activities 4, 5 and 6 for the male volunteers as their upper torso pushed back into the seatback to conduct the various activities. The relative webbing length increased by 33.2 cm ± 8.3 cm for the male and 29.1 cm ± 6.1 cm for the female volunteers in activity 3.

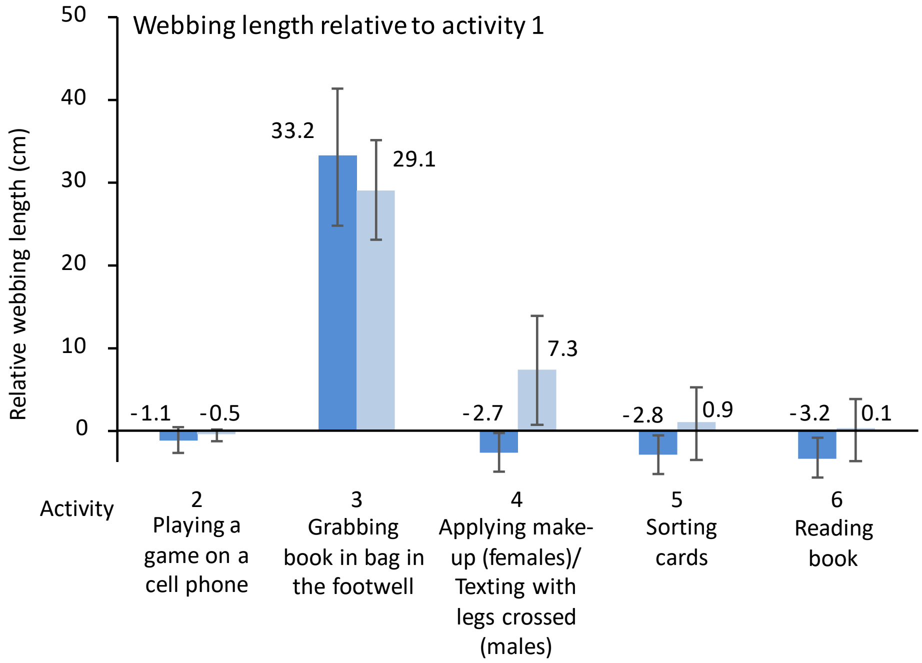


Fig. 6. Change in webbing length with respect to activity 1.

IV. DISCUSSION

This study is one of the firsts to provide insight into how teenagers sit as passengers in vehicles when engaged in different activities. Due to limited data on teenage activities, seating postures in a vehicle environment, an observational investigation was first conducted to identify activities. These included sitting normally, playing or texting with a cell phone, reaching for objects, conducting beauty related activities while using the front visor mirror, changing the radio, and brushing hair. These results were based on a small sample and the frequency of the observations was not assessed. It was noted that the rear-seat passengers were less likely to sit in a "normal" fully upright posture with their feet flat on the footwell than the front seat passenger. They were also more likely to sit with their legs crossed or with their feet resting on the console or right-front seatback.

The user study was conducted to quantify the seating posture, with specific focus on the occupant's head and torso, during observed activities. The results showed that the average resultant distance between the back of the head and the anterior surface of the head restraint varied from 2.1 ± 2.7 cm when sitting normally (activity 1) to 59.4. ± 5.9 cm when reaching for objects inside a bag placed in the footwell (activity 3) for male volunteers. The corresponding data were 3.5 ± 2.2 cm and 55.8 ± 5.1 cm for female volunteers. When the measurements were normalized by the seated height, the results seemed similar for both male and female volunteers. For example, it was 65.7% ± 8.0% for males and 65.9% ± 6.4% for females in activity 3. The results from activity 4 could not be compared by gender because the activities were different; the males were asked to text with their legs crosses while the females were asked to apply make-up while looking in the mirror on the visor. In addition to head displacement, head rotation was assessed in the user study. The measurements were reported relative to the individual volunteer's head rotation in activity 1. The head rotation was 65.3 ± 14.5 deg for males and 55.1 ± 16.9 deg for females when grabbing a book in the footwell. It was 27.2 ± 14.7 deg and 19.1 ± 8.9 deg respectively when playing a game on the cell phone.

There were no requirements when selecting the teenage volunteers other than an equal sample of males and females. Figure B1 also compares the anthropometric data of the volunteers to the ATDs [24]. The female volunteers, on average, were taller and heavier than the 5th percentile female Hybrid III. Their measurements were more comparable to the 50th percentile male Hybrid III. The average height of the male volunteers was comparable to the height of the 95th percentile male Hybrid III and the average weight of the male volunteers was comparable to the 50th percentile male Hybrid III.

Various seat concepts were proposed with the anticipation of autonomous driving vehicles. Seats that rotate or placed rear-facing have been proposed. In a frontal crash, the occupant will move forward relative to the interior or rearward relative to a rearward facing seat. When the occupant moves rearward relative to the seat, the occupant kinematics become similar to those of an occupant in a forward facing seat in a rear crash. The increase in gap between the passenger and seat/head restraint can become significant. The gap can increase the chance for the head to improperly interact with the head restraint in a rear loading and potentially result in higher forces on the head and spine. This type of mechanism has been discussed for occupants in forward facing seats involved in a rear impact [26-29]. Various studies were conducted with anthropometric test devices (ATDs). Neck forces and moments increased when the torso was leaned forward at the time of the rear impact [4,28]. Benson et al. [28] conducted a 34 km/h rear test series with a lap-shoulder belted 50th percentile male hybrid III normally seated and leaning forward. The back of the head to the head restraint distance varied from 3.8 to 10.8 cm when normally seated and was up to 50.8 cm when leaning forward. These results are less than the ones observed in this study when the volunteers were leaning forward to grab an object in the footwell (activity 3). Benson et al. [28] reported higher neck forces and moments when in the leaned forward position than in the normally seated position. The increase was greater with stiffer seats, consistent with the results reported by Viano et al. [29].

Viano et al. [29] evaluated occupant responses in 56 km/h rear delta V sled tests with the 95th male Hybrid III. The authors reported that leaning forward and inboard or outboard resulted in significant upper and lower neck responses. These results highlight the increased risk of injury when leaning forward.

The results of this study quantifies occupant-to-vehicle gaps in various activities. The results can be used to position ATDs and assess the effect of out-of-position on occupant responses. Understanding how occupants sit as passengers is an important factor to consider when investigating occupant protection in autonomous vehicles. The results also provide insight when assessing injury mechanisms of teenage passenger in the real-world vehicle crashes.

The effect of postures merits additional research in particular when related to injury outcomes, not only in vehicle crashes but also in sports for example. Shahar, Sayers [31] reported an increase in enlarged external occipital protuberance (EEOP) in 18-29 year old patients. The authors suggested that use of handheld devices may affect postures and thus musculoskeletal disorders. Berolo et al. [32] surveyed university staff and students and reported that handheld devices were used at a rate of 4.65 hour/day. About 68% of the participants reported neck pain. The mechanical loads have been found to increase by 3-5-times when seated with a flexed neck than in a neutral spine position [33].

V. CONCLUSIONS

This study identifies observed teenager activities when passengers of a vehicle. Activities included texting, looking at objects in their hands and reaching objects in the vehicle. Seven activities were simulated in a static user study with male and female teenagers. The clearance between the head and head restraint was assessed. The results showed that the back of head to the anterior surface of the head restraint varied from 2.1 cm when normally seated to 59.4 cm when grabbing a book in the footwell area for males. The corresponding range was 3.5 cm to 55.8 cm for females. In the sorting cards activity #5, the head displacement was 7.4 cm more than in the baseline activity #1. In addition to displacement, the head rotated during the various activities. Compared to the baseline activity #1, the head rotated 65 ± 15 deg for males and 55 ± 17 deg for females when grabbing a book in the footwell (activity #3). Though grabbing a book in the footwell area may not be common, teenagers are often observed interacting with electronic devices. The results from this study indicated that their head may be more forward and rotated down at that time.

VI. LIMITATION

In this study, an observational investigation was first conducted with teenage volunteers to identify activities when riding as passengers in a dynamic environment. We caution the reader that the results were based on a small sample size of volunteers. The frequency of the activities was not assessed. The effect of time of day was not assessed. The investigations were conducted in the afternoon on weekends.

In the user study, volunteers were asked to simulate selected activities in a stationary environment. The right-front door was not closed. The effect of being in a moving vehicle was not assessed. The influence of the door may affect the results. Measurements were taken based on a tape measure and video analysis of a certain time frame. Measurements were based on the location of the targets. The targets were placed near the central canal and acromion on the volunteers. However, the location of the targets could vary depending on the volunteer.

The volunteers used in this study were recruited from two different local high schools. Most of the female volunteers were from the water polo team and the male volunteers, from the crew team. Data were obtained on various size volunteers. There was no control for the height and weight. We provided all measurements in Appendix A-B. The effect of being an athlete was not assessed.

The video analysis was used in this study to assess various head and shoulder displacement relative to the seat and head restraint. Relative measurements were determined by scaling the data using the available target and/or super-imposing the checkered board on the image captures obtained from the videos. We were able to determine the displacement change along the horizontal and vertical axes. We could not account for the lateral changes. For measurements at the occupant midline, the checkerboard was used to scale the image to the appropriate size. For measurements at the head, the headrest target was used to scale the image assuming the target on the head was in the same plane. For measurements at the shoulder, the seatback target was used to scale the image, and the shoulder was assumed to be inline with the seatback target. Care was taken in the analysis to ensure each measurement was scaled to the correct depth from the camera, and not all measurements were scaled using the checkerboard in the middle of the seat. There may be some variation between the depth of head/ headrest and shoulder/seatback targets, but the difference would be minimal with the greatest scaling error up to about 5% for occupants with smaller frames. The error would decrease with larger occupants as their shoulder target would be more in line with the reference target on the seatback.

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VIII. APPENDIX

Appendix A*:* Part 1 - Observational investigation to identify teenage activities

Test Vehicle: A 2018 Equinox Sport Utility Vehicle (SUV) was used.

Human Volunteers: Four teenage volunteers, 16 to 17 years old, were used. One male volunteer was seated in the right-front and right-rear passenger seat. The three female volunteers were seated in the right-front, right-rear, and left-rear passenger seats. The volunteers were recruited from two different high schools.

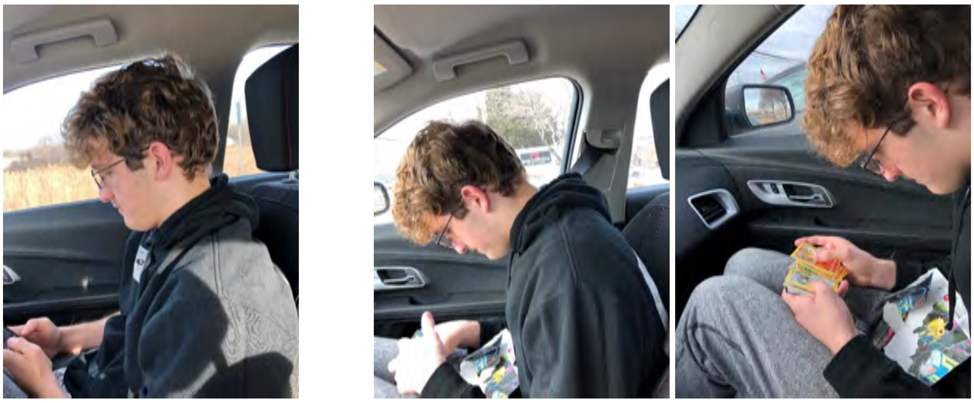
No instructions were given to the volunteers. The volunteers were allowed to adjust the right-front seat and seatback. The rear seat was not adjustable. No particular route was used but it included rural and urban roads and highways.

Driving Duration: The initial investigation was conducted with the male volunteer seated in the right-front seat during a 15-minute drive. A second investigation was conducted with the male volunteer seated in the right-rear seat during a 40-minute drive. The female volunteers were observed during a 1.5-hour drive. The female volunteers were asked to switch seats mid-way. The roadway consisted of both rural roads and highways.

Cameras: A GoPro camera was mounted to the left second-row window to capture the right second-row volunteer activities. A cell phone camera was used to capture the right-front passenger activities. The cameras were used as an observation tool. No measurements were made.

15-minute drive with male volunteer

Figure A1 shows the observed activities during the 15-minute drive with the male volunteer. It shows the volunteer bent forward to text and to look at cards.



Texting/Looking at cell phone Looking at an object (Pokemon cards)

Figure A1: Volunteer activities during the 15-minute drive.

40-minute drive with male volunteer

Figure A2 shows the observed “most common” activity of the male volunteer and Figure A3 shows the volunteer texting and/or playing with electronics such as a handheld gaming system. The volunteer’s leg was crossed, with his head oriented down at varying angles, while his torso remained supported by the seatback.

Figure A2: Male volunteer’s “most common” activity during the 40-minute drive.

Figure A3: Male volunteer playing with a handheld gaming system (left photo) and texting/looking at a cell phone (middle and right photos) during the 40-minute drive.

1.5-hour drive with female volunteers

Figures A4-A10 illustrate the observed activities with the female volunteers in the driving environment. The activities included:

1. Sitting “normally” in a relaxed position (Figure A4).
2. Playing or texting on a cell phone (Figure A5). This was the most common activity. The volunteer’s head was generally bent down in particular when the feet remained in the footwell (Figure 6, top photos). One of

the rear seat volunteers put her feet up partially resting on the console and/or seatback. With the feet supported, the volunteer rested her torso on the seatback and her head moved closer to the head restraint.

3. Grabbing objects in a schoolbag in the footwell (Figure A6). The right-front volunteer leaned forward to access the objects in the schoolbag in the footwell. The right-rear volunteer also leaned forward to look for objects in the schoolbag in the footwell area and eventually grabbed the bag and moved it on her knees for easier access.
4. Conducting beauty related activities while looking in the visor mirror (Figure A7). Examples of beauty related activities observed included applying make-up and/or facial cream and eyebrow tweezing. The scenario was only observed in the right-front seat due to the location of the visor mirror. The volunteer in the far-right photo moved the shoulder belt under her arm.
5. Looking down at an object (Figure A8). Their heads were bent down while the torso remained supported on the seatback.
6. Reaching for objects in both the right-front and right-rear seat (Figure A9).
7. Changing the radio for the right-front volunteer (Figure A10). The right-front volunteer leaned forward and inboard to change the radio.

Other activities were identified such as sleeping, hair brushing, eating and looking out the window.

Figure A4: Female volunteer seating position and posture while sitting "normally" (activity 1).

Figure A5: Female volunteer seating positions and postures while texting (activity 2).

Figure A6: Female volunteer seating positions and postures while grabbing objects from schoolbag in footwell area (activity 3).

Figure A7: Female volunteer seating positions and postures while conducting beauty related tasks (activity 4).

Figure A8: Female volunteer seating positions and postures while looking down at an object (activity 5).

Figure A9: Female volunteer seating position while reaching for objects (activity 6).

Figure A10: Female volunteer seating positions and postures while changing the radio (activity 7).

Appendix B: Part 2 - User study

The objective of the user study was to quantify teenage seating positions and postures in the most common activities related to the passenger seat and head restraint. Appendix B provides additional information on the test setup.

Test Vehicle: A stationary 2018 Equinox Sport Utility Vehicle (SUV) was used in this study. The right-front passenger seatback angle was positioned to 23 degrees, as measured from the middle of the seat back, and the head restraint was positioned in the full down position. . The seat was placed in the mid-track position.

Human Volunteers: Ten female and ten male teenage volunteers, 15 to 19 years old, were used in this study. The volunteers were placed in the right-front seat and were asked to put on the lap-shoulder belt. The volunteers were recruited from two different high schools.

Testing Protocol: The study protocol was approved by an Institutional Review Board for human-subject research at Exponent. After giving written informed consent by both the teenagers and their parents/guardians, the volunteers changed into the testing clothes. Female volunteers were asked to wear a tank top and pants and male volunteers were asked to wear only shorts for ease of locating bony landmarks. All volunteers wore a swim cap.

Measuring tools:
- Targets were placed on the swim cap, left shoulder, head restraint, seatback and D-ring.
- Inch tape was placed on the right shoulder, arm, and torso belt webbing.
- Two GoPro cameras were used to capture the occupant kinematics.
- A measuring tape was used to determine relative distances.
- A scale was placed in the center seat, photographed and removed for video analysis (Figure 1).

Figure 1: Checkered board (scale) centered in right-front seat.

Activities

The volunteers were not given any instructions about being tensed or relaxed in order to reproduce normal passenger seating positions. The volunteers were asked to perform the following activities:

1. Sitting “normally” or baseline
2. Playing a game on a cell phone to simulate texting
3. Grabbing book in bag in the footwell
4. Applying make-up while looking in the visor mirror (female)/ texting with legs crossed (males)
5. Sorting cards, simulating looking at an object
6. Reading a book

Measurements

The following measurements were determined by post-processing of the video:

- Back of head-to-anterior head restraint (HR): Gap between posterior head and head restraint along the longitudinal axis.
- Normalized back of head-to-anterior HR: Back of head-to-anterior HR divided by seated height.
- Gap between the top of the head and the top of the head restraint (vertical measurement) (activity 1 only)
- • Head target rotation: Head target rotation relative to baseline (angle at activity 1).
  - The head target rotation was assessed with respect to vertical. The absolute head angle was determined by subtracting head target angle at baseline (activity 1) to the head target angle at other postures. For example, if the initial orientation of the head target was -5 degrees in activity 1, and the head rotation in activity x was 10 degrees, the absolute angle would be 10 degrees minus -5 degrees, resulting in an absolute angle of 15 degrees of change from the baseline (activity 1) to position x.
- Head target-to-head restraint target distance (longitudinal, vertical, and resultant)
- Acromion target-to-seatback target distance (longitudinal, vertical, and resultant)

Figure B1 illustrated how the measurements were determined.

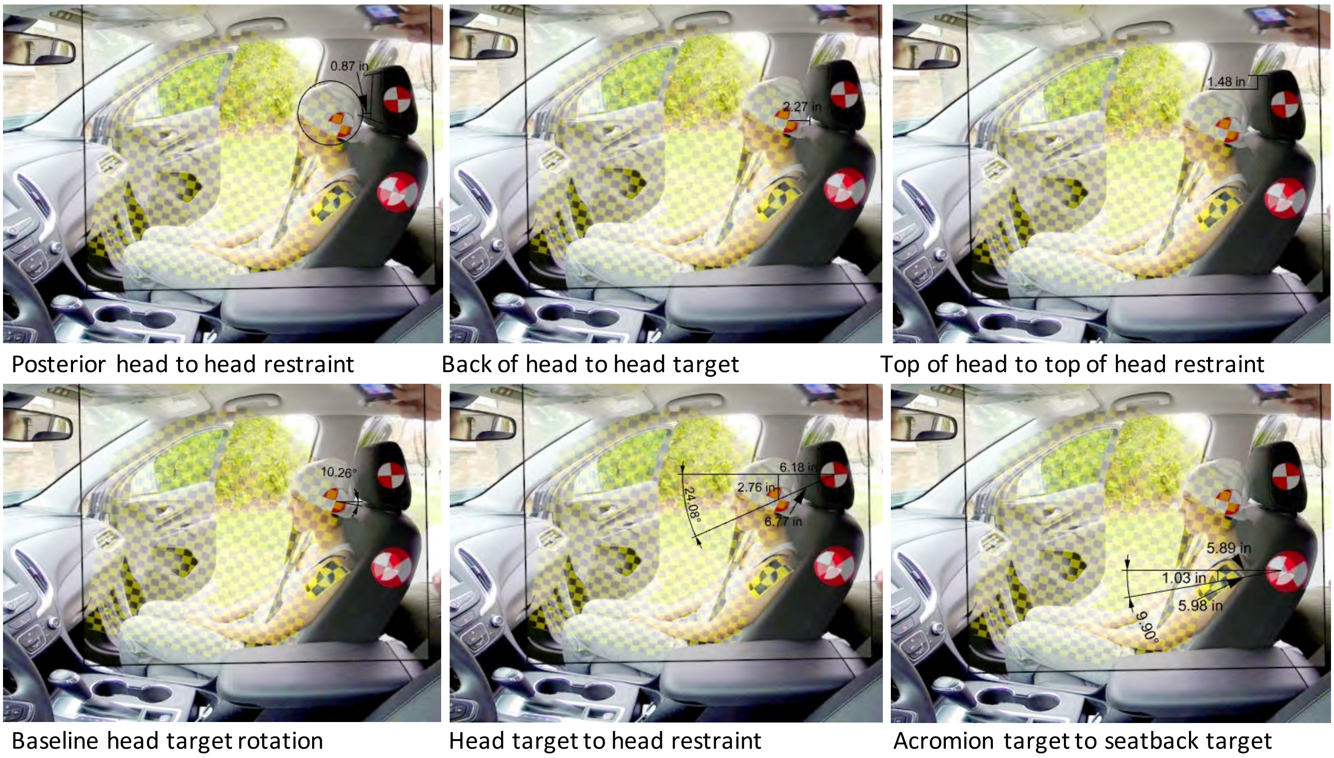


Fig B1. Example of measurements.

At the time of the user study a measuring tape was used to collect the following:

- Extracted seat belt webbing length
    - o The webbing length was representative of the amount of extracted webbing pulled out from the outboard anchor to the D-ring. Relative seat belt webbing length was determined by subtracting the webbing length at posture 1 to the webbing length at other postures. The total webbing length for was about 248 cm.
- Head target-to-head restraint target distance (resultant)
- Acromion target-to-seatback target distance (resultant)

All measurements were obtained using the center of the targets placed on the seatback, head restraint, head and acromion.

Table B1: Volunteer anthropometric measurements

#	Age	Height w shoes (cm)	Height w/o shoes (cm)	Seated Height (cm)	Weight (kg)
			Male volunteers		
1	17	185.4	186.7	94.0	83.9
3	18	185.4	180.3	91.4	72.6
6	18	177.8	175.3	91.4	68.9
13	18	189.2	187.3	96.5	74.4
14	18	181.6	177.2	94.0	72.6
15	17	182.9	181.6	90.2	78.9
16	19	175.9	174.6	91.4	87.5
18	19	181.0	179.1	85.1	70.8
19	18	193.7	190.5	88.9	84.4
20	19	181.0	179.1	83.2	70.8
Ave	18.1	183.4	181.2	90.6	76.5
sd	0.7	5.3	5.4	4.1	6.7
			Female volunteers		
2	17	175.3	175.3	86.4	59.0
4	17	154.9	152.4	81.3	47.6
5	18	165.1	162.6	86.4	44.0
7	16	177.8	175.3	83.8	70.8
8	16	163.8	162.6	85.1	69.4
9	16	184.2	182.9	91.4	90.3
10	15	170.2	167.6	81.3	65.8
11	15	175.3	172.7	87.0	89.8
12	15	162.6	160.0	78.7	46.7
17	18	165.1	162.6	85.1	53.5
Ave	16.3	169.4	167.4	84.6	63.7
sd	1.2	8.7	9.1	3.6	16.8

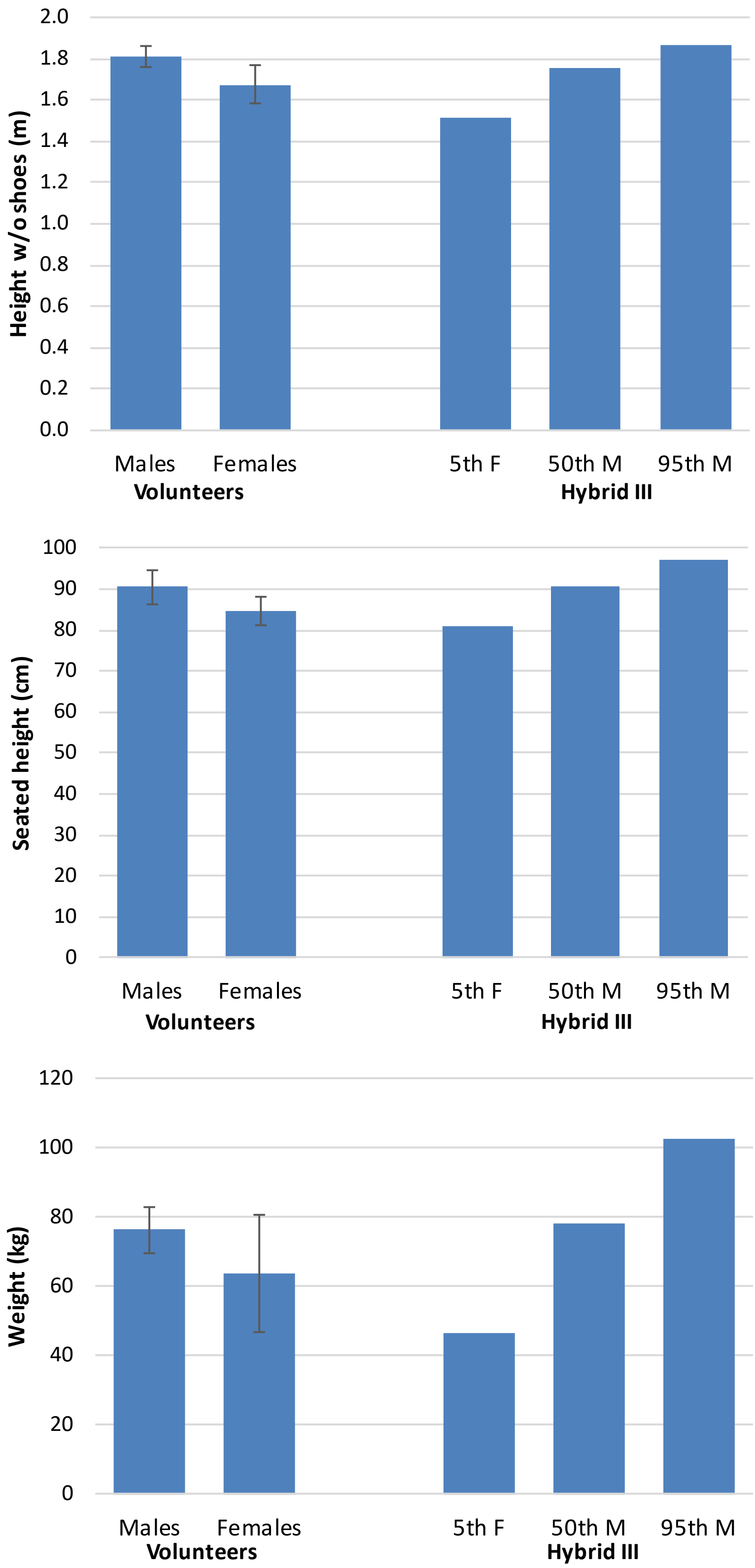


Fig B2. Volunteer anthropometric data comparison with the Hybrid III ATDs.

Measurements from video analysis:

TABLE B2

Video analysis measurements - Head-to-head restraint distance.

Head-to-Head Restraint (cm)

Activity

Vol	- Baseline			2 - Cell phone			3 - Book in bag			4 -Make-up/legs crossed			5 - Cards			6 - Book read		
#	R	X	Z	R	X	Z	R	X	Z	R	X	Z	R	X	Z	R	X	Z
									Male volunteers									
1	22	22	3	29	29	1	82	79	-22	31	31	0	27	27	0	29	29	1
3	20	18	8	26	25	6	76	76	-7	19	18	1	22	22	2	22	22	4
6	18	17	3	28	28	0	67	67	-6	22	22	-3	24	24	0	28	28	-1
13	19	17	7	30	30	0	79	78	-14	31	31	3	29	28	4	28	28	0
14	16	16	1	27	27	1	70	69	-15	24	24	1	20	20	0	27	27	-2
15	18	18	4	22	21	5	64	64	-6	28	28	4	26	25	5	24	24	2
16	16	15	6	30	30	4	82	79	-19	27	27	4	29	29	1	27	27	3
18	16	16	1	23	23	-2	77	75	-17	21	21	-3	22	21	-2	22	22	-2
19	18	18	3	21	21	0	80	78	-17	25	25	1	27	27	1	24	24	2
20	14	14	1	21	21	1	82	80	-19	23	23	1	25	25	0	16	16	1
Ave	**17.7**	**17.1**	**3.8**	**25.7**	**25.5**	**1.7**	**75.9**	**74.4**	**-14.1**	**25.0**	**24.9**	**0.9**	**25.1**	**25.0**	**1.1**	**24.7**	**24.7**	**0.8**
sd	**2.4**	**2.3**	**2.4**	**3.7**	**3.8**	**2.5**	**6.6**	**5.8**	**6.0**	**4.1**	**4.1**	**2.4**	**3.1**	**3.1**	**1.9**	**3.8**	**3.9**	**2.0**
min	**14**	**14**	**1**	**21**	**21**	**-2**	**64**	**64**	**-22**	**19**	**18**	**-3**	**20**	**20**	**-2**	**16**	**16**	**-2**
max	**22**	**22**	**8**	**30**	**30**	**6**	**82**	**80**	**-6**	**31**	**31**	**4**	**29**	**29**	**5**	**29**	**29**	**4**
									Female volunteers									
2	20	19	5	22	22	4	73	72	-7	39	38	8	28	28	2	25	25	2
4	17	16	-7	21	20	-7	65	64	-11	24	23	-7	23	22	-6	23	22	-6
5	17	17	-2	23	23	-3	81	80	-13	44	44	2	24	24	-2	24	24	-2
7	24	24	6	32	32	2	77	76	-8	38	38	5	42	42	2	36	36	3
8	18	18	-2	26	26	-6	77	75	-18	42	42	2	22	22	-4	21	19	-8
9	24	22	10	31	30	8	65	65	1	45	44	10	31	30	9	31	30	7
10	22	22	-2	22	21	-5	81	79	-20	40	40	3	46	46	2	23	23	-4
11	23	22	6	26	25	5	74	73	-14	39	38	7	52	52	1	55	55	0
12	19	18	-6	19	19	-5	65	63	-12	28	28	-2	32	32	-4	23	23	-5
17	18	17	-6	22	21	-6	74	70	-22	42	41	-3	25	24	-8	22	21	-7
Ave	**20.1**	**19.3**	**0.1**	**24.4**	**23.8**	**-1.2**	**72.9**	**71.6**	**-12.4**	**38.1**	**37.7**	**2.3**	**32.7**	**32.3**	**-0.9**	**28.2**	**27.6**	**-1.8**
sd	**2.9**	**2.8**	**6.0**	**4.2**	**4.3**	**5.5**	**6.4**	**6.0**	**6.7**	**6.9**	**7.0**	**5.3**	**10.5**	**10.8**	**5.0**	**10.3**	**10.6**	**5.0**
min	**17**	**16**	**-7**	**19**	**19**	**-7**	**65**	**63**	**-22**	**24**	**23**	**-7**	**22**	**22**	**-8**	**21**	**19**	**-8**
max	**24**	**24**	**10**	**32**	**32**	**8**	**81**	**80**	**1**	**45**	**44**	**10**	**52**	**52**	**9**	**55**	**55**	**7**

TABLE B3
Acromion-to-seatback target distance

	Acromion-to-Seatback (cm)																	
	Activity																	
Vol	1 - Baseline			2 - Cell phone			3 - Book in bag			Make-up/legs cross			5 - Cards			6 - Book read		
#	R	X	Z	R	X	Z	R	X	Z	R	X	Z	R	X	Z	R	X	Z
	volun																	
1	20	20	1	19	19	2	73	73	-2	26	26	1	20	20	0	19	17	8
3	14	13	3	14	14	2	61	60	6	15	15	-1	16	16	-2	15	15	1
6	15	15	-1	17	17	-1	49	49	4	14	14	-1	15	15	-1	16	16	-1
13	16	15	7	18	17	6	60	60	7	18	15	10	17	16	7	17	17	4
14	21	21	1	22	22	0	52	52	3	21	21	3	21	21	2	21	21	2
15	18	17	5	18	18	4	46	45	4	21	21	4	22	22	3	20	20	1
16	16	15	6	18	17	6	63	63	1	20	20	5	20	20	4	19	18	4
18	17	16	3	17	17	3	68	68	2	17	17	3	17	17	2	16	16	2
19	19	16	10	20	19	5	64	64	2	22	21	7	21	20	6	25	25	3
20	16	15	4	18	17	2	63	63	-3	18	18	1	18	18	1	17	17	1
Ave	**17.2**	**16.5**	**3.8**	**18.1**	**17.7**	**2.8**	**59.9**	**59.8**	**2.3**	**19.3**	**18.8**	**3.0**	**18.8**	**18.4**	**2.2**	**18.5**	**18.2**	**2.4**
sd	**2.3**	**2.4**	**3.1**	**2.0**	**2.0**	**2.4**	**8.5**	**8.6**	**3.2**	**3.4**	**3.6**	**3.4**	**2.3**	**2.3**	**3.0**	**3.0**	**3.0**	**2.5**
min	**14**	**13**	**-1**	**14**	**14**	**-1**	**46**	**45**	**-3**	**14**	**14**	**-1**	**15**	**15**	**-2**	**15**	**15**	**-1**
max	**21**	**21**	**10**	**22**	**22**	**6**	**73**	**73**	**7**	**26**	**26**	**10**	**22**	**22**	**7**	**25**	**25**	**8**
	Female volunteers																	
2	14	14	1	14	14	1	54	54	-4	37	37	3	18	18	0	16	16	0
4	15	15	-3	16	16	-4	47	47	-7	24	23	-5	20	19	-4	18	18	-5
5	14	14	-2	18	17	-4	54	53	-5	35	35	-2	16	16	-4	16	16	-4
7	17	17	5	16	15	5	62	62	3	23	23	1	26	24	11	19	17	8
8	15	15	0	17	17	0	57	57	-2	38	38	2	18	18	-1	18	17	-3
9	21	19	7	21	20	6	47	46	5	34	34	6	21	20	6	21	20	5
10	16	16	2	15	15	2	60	59	-6	39	38	9	32	31	6	17	17	1
11	18	16	10	21	20	6	61	61	-3	37	36	8	39	38	7	41	40	9
12	16	16	1	17	17	1	51	51	-5	28	27	5	26	26	1	22	22	1
17	14	14	2	14	14	2	56	56	-1	35	34	5	17	17	1	16	16	1
Ave	**16.1**	**15.5**	**2.4**	**16.8**	**16.4**	**1.7**	**54.8**	**54.6**	**-2.4**	**33.0**	**32.6**	**3.3**	**23.3**	**22.7**	**2.3**	**20.4**	**19.9**	**1.4**
sd	**2.3**	**1.8**	**3.9**	**2.3**	**2.0**	**3.6**	**5.3**	**5.4**	**3.9**	**6.0**	**5.9**	**4.4**	**7.5**	**7.3**	**5.0**	**7.6**	**7.4**	**4.8**
min	**14**	**14**	**-3**	**14**	**14**	**-4**	**47**	**46**	**-7**	**23**	**23**	**-5**	**16**	**16**	**-4**	**16**	**16**	**-5**
max	**21**	**19**	**10**	**21**	**20**	**6**	**62**	**62**	**5**	**39**	**38**	**9**	**39**	**38**	**11**	**41**	**40**	**9**

TABLE B4:
Initial distance

Vol	Initial distances (cm)			Head Angle - Absolute (deg)					
				Activitiy					
#	Back of head to HR	Back of head to head target	Top of head to top HR	1	2	3	4	5	6
Male volunteers									
1	7.4	7.8	7.4	0	22	75	19	23	14
3	4.0	6.5	8.5	0	22	44	8	15	11
6	0.0	10.1	7.1	0	34	57	26	26	37
13	1.2	8.6	10.4	0	45	72	41	38	39
14	0.0	8.2	5.1	0	44	77	40	34	41
15	5.2	5.6	7.6	0	3	44	16	11	7
16	0.0	7.9	8.9	0	41	80	24	38	28
18	3.0	5.2	5.7	0	35	74	28	29	28
19	0.0	10.6	8.5	0	17	78	13	24	10
20	0.0	7.2	6.5	0	10	53	13	19	3
Ave	**2.1**	**7.8**	**7.6**		**27**	**65**	**23**	**26**	**22**
sd	**2.7**	**1.7**	**1.6**		**15**	**15**	**11**	**9**	**14**
min	**0.0**	**5.2**	**5.1**		**3**	**44**	**8**	**11**	**3**
max	**7.4**	**10.6**	**10.4**		**45**	**80**	**41**	**38**	**41**
Female volunteers									
2	3.6	7.0	4.5	0	14	46	-26	22	9
4	2.2	5.8	-3.8	0	10	29	-30	6	12
5	1.4	8.1	0.2	0	32	65	1	28	29
7	6.3	7.7	6.3	0	24	42	6	35	27
8	1.4	6.1	1.2	0	30	70	-7	15	9
9	6.9	6.1	11.4	0	24	45	-4	18	18
10	4.2	8.4	1.1	0	10	71	-21	43	15
11	5.1	7.8	7.4	0	24	72	2	50	52
12	3.6	5.7	1.1	0	7	38	-20	19	15
17	0.0	7.5	1.2	0	14	75	-10	18	13
Ave	**3.5**	**7.0**	**3.1**		**19**	**55**	**-11**	**25**	**20**
sd	**2.2**	**1.0**	**4.3**		**9**	**17**	**13**	**14**	**13**
min	**0.0**	**5.7**	**-3.8**		**7**	**29**	**-30**	**6**	**9**
max	**6.9**	**8.4**	**11.4**		**32**	**75**	**6**	**50**	**52**

TABLE B5

Actual and normalized back of head to anterior surface of the head restraint distances.

Vol #	Seated Height (cm)	Delta X [cm]	Activity 1	2	3	4	5	6	Activity 1	2	3	4	5	6
			Back of Head-to-Anterior HR (cm)						Normalized Back of Head-to-Anterior HR (%)					
							Male volunteers							
1	94.0	14.9	7.4	14.0	63.9	15.8	11.9	13.9	7.8	14.9	68.0	16.8	12.6	14.8
3	91.4	14.4	4.0	10.5	61.3	4.1	7.5	7.3	4.3	11.5	67.1	4.4	8.3	8.0
6	91.4	17.4	0.0	10.6	49.2	4.7	6.7	10.7	0.0	11.6	53.8	5.2	7.3	11.7
13	96.5	16.0	1.2	13.9	61.7	15.2	12.3	12.1	1.2	14.4	63.9	15.8	12.7	12.5
14	94.0	15.6	0.0	11.7	53.4	8.3	4.6	10.9	0.0	12.5	56.8	8.8	4.9	11.6
15	90.2	12.6	5.2	8.7	51.3	15.1	12.9	11.5	5.8	9.6	56.8	16.8	14.3	12.8
16	91.4	14.5	0.0	15.5	64.9	12.0	14.8	12.5	0.0	17.0	71.0	13.2	16.2	13.6
18	85.1	13.1	3.0	9.8	61.7	7.9	8.3	8.9	3.6	11.6	72.6	9.3	9.8	10.5
19	88.9	17.6	0.0	3.6	60.6	6.9	9.7	6.3	0.0	4.1	68.2	7.8	10.9	7.1
20	83.2	14.3	0.0	6.5	65.8	8.6	10.9	2.0	0.0	7.8	79.1	10.4	13.1	2.4
Ave	**90.6**	**15.0**	**2.1**	**10.5**	**59.4**	**9.9**	**10.0**	**9.6**	**2.3**	**11.5**	**65.7**	**10.8**	**11.0**	**10.5**
sd	**4.1**	**1.6**	**2.7**	**3.6**	**5.9**	**4.4**	**3.2**	**3.5**	**2.9**	**3.7**	**8.0**	**4.6**	**3.5**	**3.7**
min	**83.2**	**12.6**	**0.0**	**3.6**	**49.2**	**4.1**	**4.6**	**2.0**	**0.0**	**4.1**	**53.8**	**4.4**	**4.9**	**2.4**
max	**96.5**	**17.6**	**7.4**	**15.5**	**65.8**	**15.8**	**14.8**	**13.9**	**7.8**	**17.0**	**79.1**	**16.8**	**16.2**	**14.8**
							Female volunteers							
2	86.4	15.5	3.6	6.6	56.8	22.6	12.8	9.0	4.2	7.6	65.7	26.2	14.8	10.5
4	81.3	13.5	2.2	6.2	50.1	9.0	8.9	8.8	2.7	7.7	61.7	11.1	10.9	10.8
5	86.4	15.5	1.4	7.7	64.1	28.6	8.8	8.6	1.6	9.0	74.2	33.1	10.2	10.0
7	83.8	17.4	6.3	14.4	58.8	20.3	24.9	18.1	7.5	17.1	70.2	24.2	29.7	21.6
8	85.1	16.5	1.4	9.0	58.4	25.9	5.1	2.5	1.6	10.6	68.6	30.5	6.0	3.0
9	91.4	15.3	6.9	14.9	49.4	28.9	14.6	14.5	7.5	16.3	54.0	31.6	15.9	15.8
10	81.3	17.3	4.2	4.1	61.3	22.5	28.8	5.5	5.2	5.0	75.4	27.6	35.5	6.7
11	87.0	16.8	5.1	8.2	56.1	21.6	35.1	37.7	5.9	9.4	64.5	24.8	40.4	43.4
12	78.7	14.1	3.6	4.7	49.3	14.2	17.7	8.9	4.6	6.0	62.5	18.0	22.5	11.3
17	85.1	16.9	0.0	3.8	53.3	24.5	7.2	4.0	0.0	4.4	62.6	28.8	8.4	4.7
Ave	**84.6**	**15.9**	**3.5**	**8.0**	**55.8**	**21.8**	**16.4**	**11.8**	**4.1**	**9.3**	**65.9**	**25.6**	**19.4**	**13.8**
sd	**3.6**	**1.3**	**2.2**	**3.9**	**5.1**	**6.2**	**10.1**	**10.2**	**2.6**	**4.3**	**6.4**	**6.7**	**12.0**	**11.7**
min	**78.7**	**13.5**	**0.0**	**3.8**	**49.3**	**9.0**	**5.1**	**2.5**	**0.0**	**4.4**	**54.0**	**11.1**	**6.0**	**3.0**
max	**91.4**	**17.4**	**6.9**	**14.9**	**64.1**	**28.9**	**35.1**	**37.7**	**7.5**	**17.1**	**75.4**	**33.1**	**40.4**	**43.4**

TABLE B6
Head and acromion data relative to activity 1.

Vol	Head-to-HR (cm)					Head angle (deg) relative to activity 1					Acromion-to-seat (cm)				
	Activity					Activity					Activity				
#	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
Male volunteers															
1	6.4	59.4	8.3	4.3	6.3	-5.6	8.3	-7.3	-6.6	-6.0	-0.9	53.1	6.0	0.5	-1.1
3	5.8	56.2	-1.4	2.2	2.3	-8.5	-17.1	-20.7	-18.0	-11.6	0.5	46.7	1.7	8.4	1.1
6	10.3	49.1	4.5	6.4	10.4	-10.8	-5.8	-4.5	-10.1	-8.8	1.9	34.2	-0.8	1.3	0.8
13	11.3	60.3	12.6	9.9	9.4	-22.1	-12.8	-17.9	-15.7	-22.1	1.9	44.0	1.8	1.1	1.3
14	11.7	54.8	8.2	4.5	10.9	-4.4	6.4	-3.2	-5.5	-1.9	0.8	30.4	0.1	-0.6	0.0
15	3.5	45.7	9.7	7.5	5.8	-0.7	-8.7	-5.4	-3.5	-10.0	-0.2	27.6	3.1	3.9	1.9
16	14.7	66.2	11.2	13.8	11.6	-14.1	-7.6	-13.4	-18.3	-14.8	1.6	47.0	4.0	3.7	2.3
18	6.9	60.7	5.1	5.4	6.0	1.2	9.7	5.5	2.7	2.1	0.7	51.1	0.1	0.8	-0.5
19	3.4	62.2	6.8	9.5	6.2	-7.7	3.4	-5.3	-6.2	-3.6	1.2	45.5	3.3	2.1	6.2
20	6.5	67.9	8.6	10.8	2.0	-2.0	8.3	-2.7	-4.9	-2.5	1.8	47.5	2.5	2.5	1.3
Ave	8.0	58.3	7.4	7.4	7.1	-7.5	-1.6	-7.5	-8.6	-7.9	0.9	42.7	2.2	2.4	1.3
sd	3.8	7.0	4.0	3.6	3.4	6.9	9.9	7.8	6.8	7.1	1.0	8.8	2.1	2.5	2.0
min	3.4	45.7	-1.4	2.2	2.0	-22.1	-17.1	-20.7	-18.3	-22.1	-0.9	27.6	-0.8	-0.6	-1.1
max	14.7	67.9	12.6	13.8	11.6	1.2	9.7	5.5	2.7	2.1	1.9	53.1	6.0	8.4	6.2
Female volunteers															
2	2.7	52.9	19.2	8.6	4.9	-4.3	-8.4	-3.0	-10.0	-8.5	0.2	40.1	23.1	3.8	2.6
4	3.7	47.4	6.4	6.1	5.9	-4.7	-14.3	-6.9	-8.1	-8.9	1.0	32.1	8.5	4.6	3.0
5	6.4	63.7	27.1	7.4	7.1	-0.1	1.7	-5.5	-2.6	-3.9	3.7	39.6	21.3	2.4	2.2
7	7.4	52.1	13.6	17.9	11.2	-9.9	-7.8	-6.5	-10.7	-8.8	-1.5	44.3	5.8	8.9	1.1
8	8.2	58.9	24.4	4.0	2.6	5.6	6.3	-5.0	4.2	15.6	1.4	41.6	23.1	2.3	2.3
9	6.9	40.4	21.0	6.9	6.4	-9.0	-22.7	-11.4	-6.9	-10.0	-0.1	25.8	13.6	0.1	0.4
10	0.2	59.4	18.3	24.5	1.4	5.8	7.8	-1.4	-4.3	2.9	-0.8	43.7	23.4	15.7	0.6
11	2.8	51.5	16.2	29.1	31.8	-3.5	-4.8	-5.1	-14.8	-15.3	2.2	42.6	18.3	20.6	22.7
12	0.8	46.0	9.7	13.4	4.8	-4.1	-7.1	-13.5	-11.0	-6.8	0.8	35.1	11.5	10.0	5.3
17	3.8	55.7	23.8	7.6	4.2	-1.5	-0.8	-13.6	0.0	0.2	0.6	42.0	21.0	3.7	2.4
Ave	4.3	52.8	18.0	12.6	8.0	-2.6	-5.0	-7.2	-6.4	-4.4	0.7	38.7	17.0	7.2	4.3
sd	2.8	7.0	6.6	8.6	8.8	5.3	9.3	4.2	5.8	8.7	1.5	5.9	6.6	6.6	6.6
min	0.2	40.4	6.4	4.0	1.4	-9.9	-22.7	-13.6	-14.8	-15.3	-1.5	25.8	5.8	0.1	0.4
max	8.2	63.7	27.1	29.1	31.8	5.8	7.8	-1.4	4.2	15.6	3.7	44.3	23.4	20.6	22.7

Measurements from measuring tape:

TABLE B7
Resultant measurements taken with a tape measure during the user study

	Head-to-HR (cm)						Acromion-to-seat (cm)						Webbing Length (cm)					
	Activity						Activity						Activity					
#	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Male volunteers																		
1	22.2	28.6	80.0	27.9	27.9	26.0	21.6	20.3	69.9	25.4	20.3	19.1	139.7	137.2	180.3	137.2	134.6	135.3
3	17.1	23.5	71.1	17.8	19.1	20.3	15.2	14.6	55.9	15.2	15.9	15.2	141.6	142.2	164.5	142.2	140.3	139.7
6	14.6	24.1	64.8	21.0	21.6	25.4	14.6	16.5	47.0	14.0	14.0	15.2	--	139.7	161.3	135.3	134.0	135.9
13	17.8	27.3	76.2	29.2	27.3	27.3	16.5	17.8	58.4	17.1	17.1	17.1	134.6	135.3	172.1	134.6	134.6	134.6
14	14.6	26.7	64.8	22.2	19.7	25.4	20.3	21.6	48.3	20.3	19.1	20.3	134.6	134.0	163.8	131.4	133.4	133.4
15	17.8	20.3	59.7	26.0	22.9	22.9	19.1	19.1	41.9	21.6	23.5	21.6	134.6	133.4	153.7	130.8	130.8	130.8
16	15.2	26.7	83.2	26.7	29.2	24.8	17.1	17.8	60.3	19.7	20.3	19.1	140.3	139.7	178.4	139.7	139.7	139.7
18	17.8	22.9	76.8	19.7	21.0	20.3	16.5	16.5	66.0	15.9	17.1	15.2	137.2	136.5	178.4	132.1	133.4	132.1
19	15.2	19.1	80.6	24.1	26.0	22.9	19.1	20.3	63.5	21.6	20.3	24.8	146.7	142.2	181.6	140.3	139.7	139.7
20	15.2	20.3	76.2	22.2	24.1	15.9	15.2	17.1	58.4	17.1	17.1	15.9	135.3	134.6	170.2	132.1	133.4	130.2
Ave	16.8	23.9	73.3	23.7	23.9	23.1	17.5	18.2	57.0	18.8	18.5	18.4	138.3	137.5	170.4	135.6	135.4	135.1
sd	2.3	3.3	7.9	3.7	3.6	3.5	2.4	2.1	8.9	3.5	2.8	3.2	4.2	3.3	9.4	4.1	3.3	3.6
Female volunteers																		
2	18.4	20.3	69.9	34.9	26.0	22.9	13.3	14.0	51.4	35.6	17.8	16.5	134.6	134.6	162.6	146.1	132.1	132.1
4	16.5	16.5	63.5	20.3	21.6	20.3	12.7	14.0	48.3	21.6	17.8	16.5	134.0	134.0	153.7	133.4	133.4	133.4
5	15.2	21.6	77.5	39.4	22.9	21.6	12.7	13.3	55.2	34.9	15.2	15.2	--	133.4	166.4	141.0	135.9	134.6
7	21.6	27.9	79.4	32.4	36.8	31.8	17.8	16.5	62.2	24.1	25.4	18.4	142.2	142.9	175.9	144.1	144.1	141.6
8	16.5	20.3	73.7	38.1	20.3	19.1	15.2	16.5	55.9	36.8	15.9	16.5	141.0	141.0	176.5	157.5	143.5	144.1
9	21.6	27.9	61.0	40.6	27.9	27.9	20.3	20.3	43.2	33.0	20.3	20.3	157.5	156.2	181.6	169.5	157.5	157.5
10	19.1	20.3	76.2	38.7	42.5	20.3	15.2	14.0	57.2	36.8	30.5	15.9	142.9	142.2	181.6	157.5	151.1	142.9
11	21.6	22.9	67.3	37.5	48.3	51.4	19.1	20.3	64.8	34.9	37.5	40.0	160.7	160.0	190.5	166.4	167.0	168.3
12	17.8	18.4	61.0	27.3	26.7	22.9	15.2	15.9	48.3	27.3	24.1	21.6	134.6	134.0	158.8	133.4	133.4	134.6
17	17.8	21.0	73.7	39.4	24.8	20.3	11.4	13.3	53.3	33.0	17.1	14.6	137.2	135.3	165.1	142.2	130.8	130.8
Ave	18.6	21.7	70.3	34.9	29.8	25.8	15.3	15.8	54.0	31.8	22.2	19.6	142.7	141.4	171.3	149.1	142.9	142.0
sd	2.3	3.7	6.8	6.5	9.5	9.8	2.9	2.7	6.6	5.5	7.2	7.5	9.9	9.6	11.7	12.9	12.3	12.2