A THREE DIMENSIONAL ANALYSIS OF RIDING POSTURE ON THREE DIFFERENT STYLES OF MOTORCYCLE

Terry Smith, John Zellner
Dynamic Research, Inc.
Torrance, California, USA

Nicholas M. Rogers
International Motorcycle Manufacturers Association
Geneva, Switzerland

International Motorcycle Safety Conference
March 2006

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ABSTRACT

Effective motorcycle and personal protective equipment design depends heavily upon understanding the geometric relationship between the motorcycle and the motorcycle rider. Basic human factors issues such as forward vision, riding comfort, control location and operation all require knowledge of riding posture while operating a motorcycle. This study reports on the results of a study to determine the three dimensional location and orientation of body segments for nine motorcycle riders while sitting on one of three different motorcycles. Each subject had anthropometric characteristics that closely matched the 50th percentile MATD dummy used for ISO 13232 testing. Each subject was asked to assume a most comfortable riding position followed by a maximum forward and maximum rearward riding position on a conventional, sport and cruiser motorcycle. Twenty-eight reflective markers were placed on specific anatomical landmarks on the subject's body and a calibrated 5 camera photogrammetry system was used to locate these markers in a 3 dimensional space. A total of 170 trials were conducted and these results were compared to a series of tests collected on the same motorcycles with the MATD dummy used for ISO 13232 testing. The data from this study provide unique three dimensional anthropometric data that could be used for future human factors motorcycle research. The results also suggest that improvements could be made to the existing MATD dummy to make it more closely match the anthropometric characteristics of a 50th percentile male motorcycle rider.

INTRODUCTION

The Motorcycle Anthropometric Test Dummy (MATD) has been developed specifically for motorcycle crash testing in accordance with the ISO 13232 standard. The original MATD design was based largely upon the existing Hybrid III Anthropometric Test Dummy design; therefore, it was assumed that the anthropometric characteristics of the MATD resembled a 50th percentile motorcycle rider; however, no study has ever confirmed this assumption.

Very little published data exists regarding motorcycle rider anthropometry. The only published motorcycle specific anthropometric study (other than the study described above) was completed by Robertson and Miller (1996). They conducted a survey of 140 motorcyclists in the United Kingdom and collected six body dimensions that they believed to be relevant to the design of future motorcycles. These dimensions were related to operation of the controls of the motorcycle (e.g. acromion to grip length, knee height above the ground, buttock to knee length) and did not include any measurements related to the neck (e.g. seated head height).

While this data provided excellent general information regarding general riding postures, additional data was needed in order to compare the MATD characteristics with those of 50th percentile male motorcycle riders. Therefore, it was the objective of this research project to collect this information and relate it to the databases and research described above.

In addition, discussions in ISO/TC22/SC22/WG22 indicated that questions regarding whether the new MATD modified neck was of the proper length. Ad hoc tests with three mid-size male subjects had been done to size the new neck geometry (Withnall et al., 2003); however, there were questions regarding the representativeness of those results and of the neck geometry in general.

METHODOLOGY

Subject recruitment and data collection

A total of nine subjects were selected for this project. All subjects were experienced motorcycle riders and all subjects possessed height and weight characteristics similar to a 50th percentile adult male. In several cases the subject's weight was either above or below the target weight range of 73.6 to 80.5 kg. Since the subjects met the 50th percentile adult male height requirements (i.e. they were between 172.7 cm and 177.8 cm) and the major skeletal landmarks were used to ascertain segment lengths, body mass was not considered to be a major factor that would influence overall neck length. A detailed description of the general characteristics of each subject is presented in Table 1.

Table 1: Characteristics of Test Subjects

Subject ID	Age (yrs)	Riding Experience (yrs)	Height (cm)	Weight (kg)
96-1	41	15	177.8	72.6
96-2	39	31	174.3	73.0
96-3	58	35	176.5	81.6
96-4	48	35	177.8	68.9
96-5	29	14	172.7	74.8
96-6	54	1	175.9	76.4
96-7	37	10	178.4	79.4
96-8	44	19	174.9	67.1
96-9	54	27	175.3	69.9
Mean value	44.9	20.8	176.0	73.8
Standard Deviation	9.4	11.9	1.9	4.8

Prior to testing, all subjects were informed of the nature of the study as well as the risks associated with participating in the study. If the subject agreed to participate in the study, a consent form was signed by the subject and the subject was asked to change into the cycling shorts and running shoes.

Reflective markers were then applied to the major anatomical landmarks of the subject's body. Landmarks were located by direct palpation of the rider's body. A complete list of the landmarks used in this study appears in Table 2.

Table 2: Anatomical Landmarks Used During Human Subject Testing

Landmark
Infraorbitale – left
Tragion – left
Cervicale (C7)
Manubrium
Acromion – left
Lateral humeral epicondyle - left
Lateral ulnar styloid – left
ASIS – left
Trochanterion – left
Lateral femoral epicondyle - left (knee joint)
Tibial tuberosity – left
Lateral malleolus - left (ankle joint)
Calcaneous - left (heel)
5th metatarsal head - left
Distal portion of digit II on foot - left
Infraorbitale – right
Tragion – right
Acromion – right
Lateral humeral epicondyle - right
Lateral ulnar styloid – right
ASIS – right
Trochanterion – right
Lateral femoral epicondyle - right (knee joint)
Tibial tuberosity – right
Lateral malleolus - right (ankle joint)
Calcaneous - right (heel)
5th metatarsal head - right
Distal portion of digit II on foot - right

Once all anatomical markers had been applied, the subject was then brought to the test area where one of three subject motorcycles was mounted onto a platform. Each motorcycle was rolled onto the platform and secured in an upright position while the rider sat on the motorcycle using “tie-downs” at each corner of the wooden platform. The motorcycles that were chosen for this project were a Yamaha SR500, a Yamaha FZR 600 and a Harley Davidson Road King.

The subjects were informed that photographs were going to be taken of them in various riding positions. The subjects were instructed that the first position represented their most natural or most comfortable riding posture for that particular motorcycle. The second trial represented the forward most riding posture that they would assume while the third trial represented the most rearward posture that they would assume for that motorcycle. Following these three trials, the subjects were asked to assume intermediate postures between these two extreme postures. In general, a minimum of five trials were collected for each subject.

For all trials, subjects were asked to assume that they were operating the motorcycle and looking straight ahead. A target was placed on the curtain directly in front of the rider at a height of 1.2 m. Riders were instructed to look forward to that they could see the target, but not necessarily to fix their gaze upon the target. It was felt that this approach ensured that the rider’s head would remain upright throughout the entire range of seating positions.

Once the subject had assumed the desired posture, they were asked to hold that posture steady while five 35 mm SLR cameras took still images of the rider. The cameras were located at strategic locations around the platform such that each anatomical marker was captured on film by at least two of the SLR cameras. These still images were used for the identification of the three dimensional location of each anatomical landmark located on the human subject.

As indicated above, five simultaneous photographs were taken of each subject in each riding position on each test motorcycle. In order to locate the anatomical landmarks for each subject in three dimensional space, it was necessary to calibrate each captured image. This was accomplished by using a three dimensional calibration frame which included 25 points that were known in a three dimensional reference frame. Calibration data was collected immediately prior to and immediately following each subject session in order to ensure that any movement in the camera positions could be accounted for.

MATD Measurement

In order to make comparisons to the MATD and the human subjects, it was necessary to repeat the exact same test procedures using the MATD. Specific landmarks were chosen on the MATD and these landmarks were used for the subsequent comparisons to the human test subjects. A complete listing of all MATD landmarks appears in Table 3.

Table 3: MATD surface landmarks

Base of eye socket (left and right)
Nodding pin (left and right)
Front of lowest plate on MATD neck
Top of MATD spine box
Top of shoulder cap bolt (left and right)
Centre of elbow joint (left and right)
Center of wrist joint (left and right)
H-point (left and right)
Centre of knee joint (left and right)
Centre of ankle joint (left and right)
Fifth metatarsal joint (left and right)
Distal portion of digit II (left and right)

The exact same motorcycles and test protocol were used for the MATD testing. The MATD was positioned on the subject motorcycle using the procedures defined in ISO 13232. Once the dummy was properly positioned the same five cameras were used to take simultaneous photographs of the dummy while in the ISO standard test position. These procedures were then repeated for the other two motorcycles.

Motorcycle Measurement

In addition to measurement of the human subjects and the MATD, several landmarks were identified on the subject motorcycles. It was felt that this additional information was useful to locate both the human subjects and the MATD relative to known points on the motorcycle. A complete list of all motorcycle landmarks is found in Table 4.

Table 4: Motorcycle Landmarks

Front axle (left and right side)
Engine case (left and right side)
Gas tank (left and right side)
Rear axle (left and right side)
Footpeg (left and right side)
End of handgrip (left and right side)
Fork centerline at the steering head

Data reduction

Each image that was taken by the 35 mm cameras was developed and converted into a digital image file at the time of film processing. Each digital image was then transferred to a PC computer and all landmarks seen on the image were digitized using a commercially available software package (PhotoWin35). The digitizing process consisted of identifying the landmark in the image space using a mobile cursor and generating x,y image space coordinates for each of the anatomical landmarks that were visible in a given image. Once the user had identified the desired x,y location for a given coordinate, the software package stored the information to a coordinate file for each digital image.

In addition to the anatomical and motorcycle landmarks, a known fixed and immobile reference point was also digitized in each image. This was done in order to correct for any image shifting which may have taken place during the digitizing process. Upon completion of the digitizing for a given subject trial, any image shifting was then corrected using the known fixed reference point.

The three dimensional coordinates were generated using a direct linear transform technique. This mathematical technique uses the known calibration coordinates in the three dimensional object space to solve a set of equations which were used to determine the three dimensional location of any landmark which appeared in the two dimensional images. The object space reference frame was generated according to SAE conventions with x being positive and to the right, y being positive upwards and z being positive to the right (i.e. a right hand coordinate system).

Once the three dimensional coordinates for each of the anatomical landmarks were determined, the location of the centre of gravity of the head and the location of the atlanto-occipital joint were computed using algorithms that have been published elsewhere (Walker et al., 1973, Thunnissen et al., 1995). Once these measures were computed, several other anthropometric measures were computed. A complete list of all computed anthropometric measures appears in Table 5. All segment angles were computed and expressed using the ISO 13232 reporting convention for angles (i.e. the angle is expressed relative to the vertical).

Table 5: Computed anthropometric measures

Distance from the shoulder joint to head centre of gravity (m)
Angle of the shoulder joint to head centre of gravity segment (deg)
Distance from the shoulder joint to the occipital condyle (m)
Angle of the shoulder joint to occipital condyle segment (deg)
Distance from the H-point to the head centre of gravity (m)
Angle of the H-point to head centre of gravity segment (deg)
Distance from the H-point to the tragion (m)
Angle of the H-point to tragion segment (deg)
Distance from the H-point to the occipital condyle (m)
Angle of the H-point to occipital condyle segment (deg)
X,Y,Z distance from the subject left infraorbitale to the MATD left infraorbitale (cm)
Out of plane angle (degrees)

In addition to computed anthropometric measures, a direct comparison was made between the seated MATD and the human subjects positioned in their most comfortable riding position. The location of the front axle of each motorcycle was used as a reference to properly locate motorcycle in three dimensions for both the human subject trials and the MATD trials. The infraorbitale marker was then identified on both the human subjects and the MATD, and the location of the infraorbitale of the human subjects relative to the location of the MATD infraorbitale was computed in three dimensions.

RESULTS

The computed segment lengths for all subjects across all trials and all motorcycles is illustrated in Table 6. The segment lengths partitioned according to motorcycle type is presented in Table 7.

Table 6: Human Subject Segment Length Data – All Trials.

Parameter	C_7T_1 to head cg (m)	C_7T_1 to occipital condyle (m)	H-point to head cg (m)	H-point to tragion (m)	H-point to occipital condyle (m)
N	163	163	170	170	170
Mean	.159	.137	.675	.648	.624
Median	.160	.138	.674	.647	.624
Maximum	.220	.173	.772	.743	.719
Minimum	.116	.084	.611	.584	.560
Std Dev	.014	.015	.030	.030	.030

Table 7: Human Subject Segment Length Data Sorted by Motorcycle Type

Motorcycle	Parameter	C_7T_1 to head cg (m)	C_7T_1 to occipital condyle (m)	H-point to head cg (m)	H-point to tragion (m)	H-point to occipital condyle (m)
Cruiser	N	55	55	57	57	57
	Mean	.158	.141	.669	.642	.618
	Median	.160	.142	.663	.636	.614
	Maximum	.186	.166	.732	.703	.678
	Minimum	.127	.109	.611	.583	.560
	Std Dev	.012	.014	.027	.027	.027
Sport	N	53	53	56	56	56
	Mean	.159	.131	.679	.650	.626
	Median	.160	.132	.681	.652	.628
	Maximum	.220	.173	.772	.743	.719
	Minimum	.116	.084	.622	.594	.570
	Std Dev	.018	.016	.033	.033	.033
Conventional	N	55	55	57	57	57
	Mean	.160	.139	.679	.651	.628
	Median	.161	.141	.678	.649	.625
	Maximum	.182	.162	.743	.714	.689
	Minimum	.127	.091	.626	.598	.574
	Std Dev	.012	.015	.029	.029	.029
All Trials	N	163	163	170	170	170
	Mean	.159	.137	.676	.648	.624
	Median	.160	.138	.674	.648	.624
	Maximum	.220	.173	.772	.743	.719
	Minimum	.116	.084	.611	.583	.560
	Std Dev	.014	.015	.030	.030	.030

Table 8 illustrates the segment angles for all subjects across all trials. Table 9 illustrates these same segment angles when sorted by motorcycle type.

Table 8: Segment angle information for all subjects across all trials.

Parameter	C_7T_1 to head cg angle (deg)	C_7T_1 to occipital condyle angle (deg)	H-point to head cg angle (deg)	H-point to tragion angle (deg)	H-point to occipital condyle angle (deg)
N	163	163	170	170	170
Mean	44.3	55.8	55.3	55.6	55.7
Median	38.2	56.9	52.0	52.4	52.4
Maximum	96.2	85.1	92.4	93.4	94.2
Minimum	13.2	23.0	16.6	15.7	14.7
Std Dev	19.7	14.0	20.9	21.5	22.0

Table 9: Segment angle information sorted by motorcycle type

Motorcycle	Parameter	C_7T_1 to head cg angle (deg)	C_7T_1 to occipital condyle angle (deg)	H-point to head cg angle (deg)	H-point to tragion angle (deg)	H-point to occipital condyle angle (deg)
Cruiser	N	55	55	57	57	57
	Mean	49.6	60.7	64.1	64.6	64.9
	Median	44.5	59.5	68.8	69.3	69.7
	Maximum	96.2	85.1	92.4	93.4	94.2
	Minimum	13.2	28.9	29.8	29.2	28.6
	Std Dev	20.4	13.2	19.8	20.4	21.0
Sport	N	53	53	56	56	56
	Mean	35.4	49.4	42.4	42.3	42.0
	Median	34.0	50.2	43.3	43.5	43.5
	Maximum	77.8	76.5	67.5	68.1	68.4
	Minimum	15.1	23.0	18.3	17.5	16.7
	Std Dev	14.3	13.5	13.3	13.7	14.0
Conventional	N	55	55	57	57	57
	Mean	47.5	57.0	59.2	59.6	59.8
	Median	39.3	55.4	61.1	61.2	61.1
	Maximum	91.0	83.0	91.0	92.4	93.6
	Minimum	21.3	33.6	16.6	15.7	14.7
	Std Dev	20.9	12.9	22.1	22.7	23.3

Figure 1 illustrates the changes in neck length as the angle of the back increases. Relative to the test protocol and the sign convention used in ISO13232 this figure illustrates the neck length as the rider leans farther forward relative to the horizontal axis. The data clearly shows that with relative few exceptions, as the rider moves forward, the neck length increases.

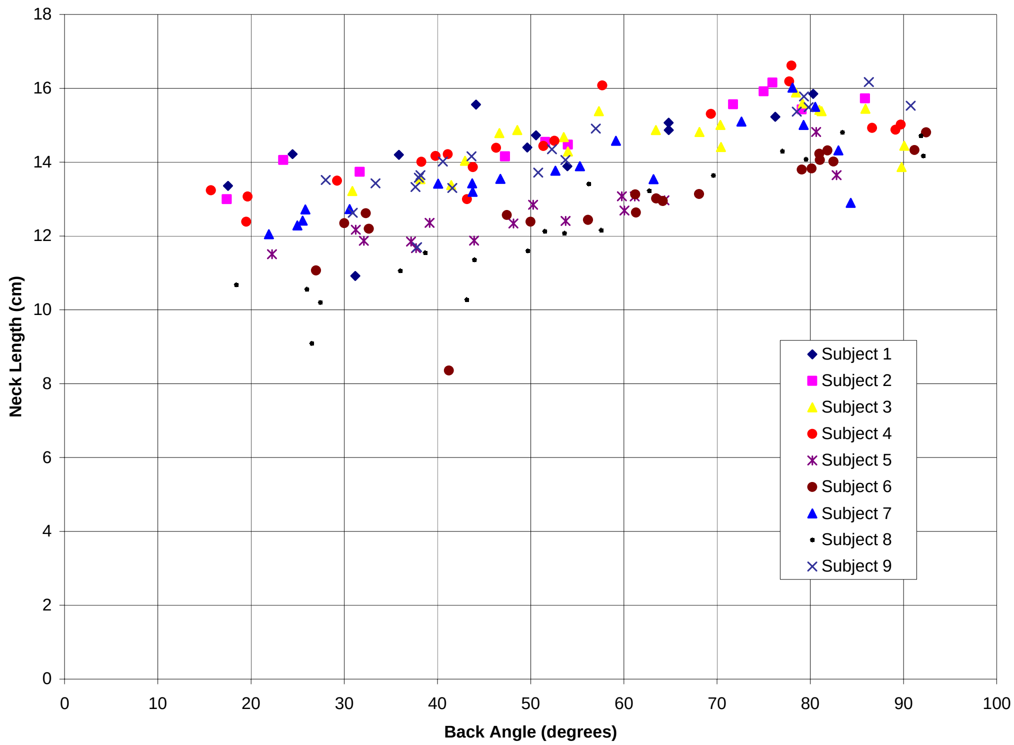

Figure 1. Rider neck length as a function of back angle (all trials).

Comparison to MATD measures

Concurrently with the human subject measurements, similar measurements were taken for the MATD when positioned on the subject motorcycle according to the protocols established by ISO 13232. Identical images were taken of the MATD and processed in an identical manner to the human subjects.

As a method to compare the position of the human subjects relative to the MATD, the location of the subject infraorbitale marker relative to the MATD was computed for all cases. Figure 2 illustrates this procedure by comparing the MATD in the ISO 13232 position and the test subject in a natural riding position.

Figure 2. Illustration of comparison of human subject position relative to MATD ISO13232 position.

The sign convention applied to this analysis was identical to the sign convention used for ISO 13232 and is illustrated in Figure 3.

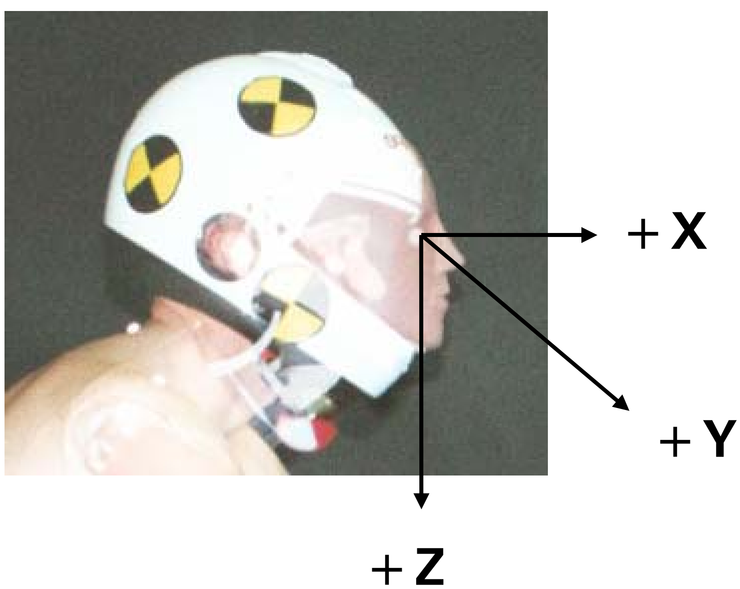

Figure 3. Sign convention to determine infraorbitale location relative to MATD.

Figure 4 provides an illustration of the position of the human subject infraorbitale relative to the MATD infraorbitale with a 95 percent confidence interval across all trials.

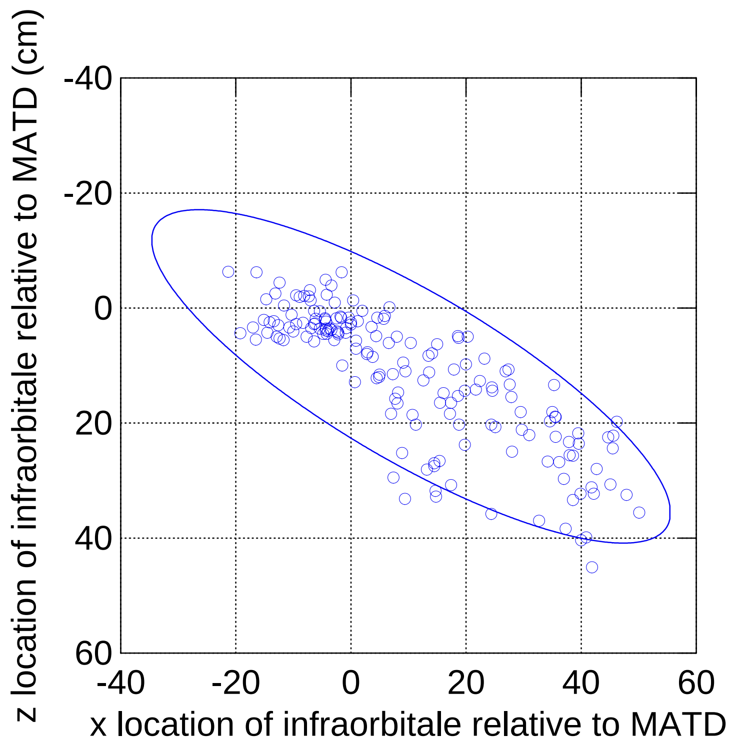

Figure 4. 95 percent confidence interval of x,z location of human subject infraorbitale relative to MATD (all trials).

Table 10: Summary of x,y,z location of infraorbitale relative to MATD (all trials)

Parameter	X location of infraorbitale relative to MATD (cm)	Y location of infraorbitale relative to MATD (cm)	Z location of infraorbitale relative to MATD (cm)
N	170	170	170
Mean	10.45	-2.80	11.89
95% CI_{lower}	7.69	-3.31	10.11
95% CI_{upper}	13.20	-2.29	13.66
Median	7.15	-2.60	8.15
Std Dev	18.20	3.36	11.70
Maximum	50.10	-11.50	45.10
Minimum	-21.30	6.10	-6.30
Range	71.40	17.60	51.40

The data indicates that across all trials, the mean distance from the human subject infraorbitale marker and the MATD infraorbitale marker is 10.5 cm in the x direction, -2.8 cm in the y direction and 11.9 cm in z direction. To describe this in another way, the data shows that the location of the human subject infraorbitale is 10.4 cm in front of and 11.9 cm below the current MATD infraorbitale position. Laterally, the human subject infraorbitale appears to be located 2.8 cm to the left of the current MATD infraorbitale position.

The data was further analyzed by comparing human subject infraorbitale position and MATD infraorbitale position by motorcycle type and comparing infraorbitale position when the rider is in his most comfortable or most natural riding position (see Figure 5).

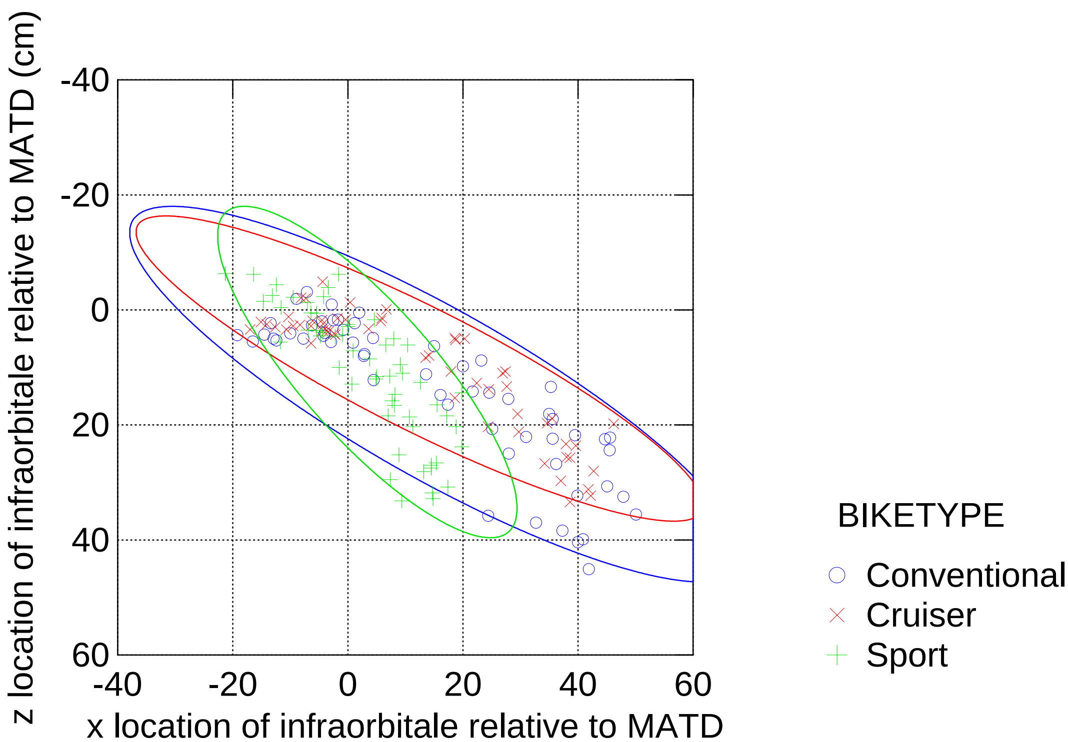

Figure 4. 95 percent confidence interval of x,z location of human subject infraorbitale relative to MATD (sorted by motorcycle type).

The data shows that the dispersion of location appears to be the greatest for the conventional motorcycle, followed by the cruiser motorcycle. The motorcycle which has the least amount of dispersion throughout all subjects and all riding positions, is the sport motorcycle.

It is important to note that this aggregate data represents the forward-most and rearward most positions of all human subjects. When the data for the most comfortable riding position is used, the spread within the data becomes much less. Figure 5 illustrates the 95 percent confidence interval of the x,z location of the infraorbitale relative to the MATD. When riders are in their most comfortable riding position, the mean distance from the human subject infraorbitale marker and the MATD infraorbitale marker is -0.33 cm in the x direction, -2.4 cm in the y direction, and 5.2 cm in the z direction. Therefore, the data shows that when the rider is in his most comfortable riding position, the location of the human subject infraorbitale is 0.33 cm in front of and 5.2 cm below the current MATD infraorbitale position. Laterally, the human subject infraorbitale is located 2.4 cm to the left of the current MATD infraorbitale position.

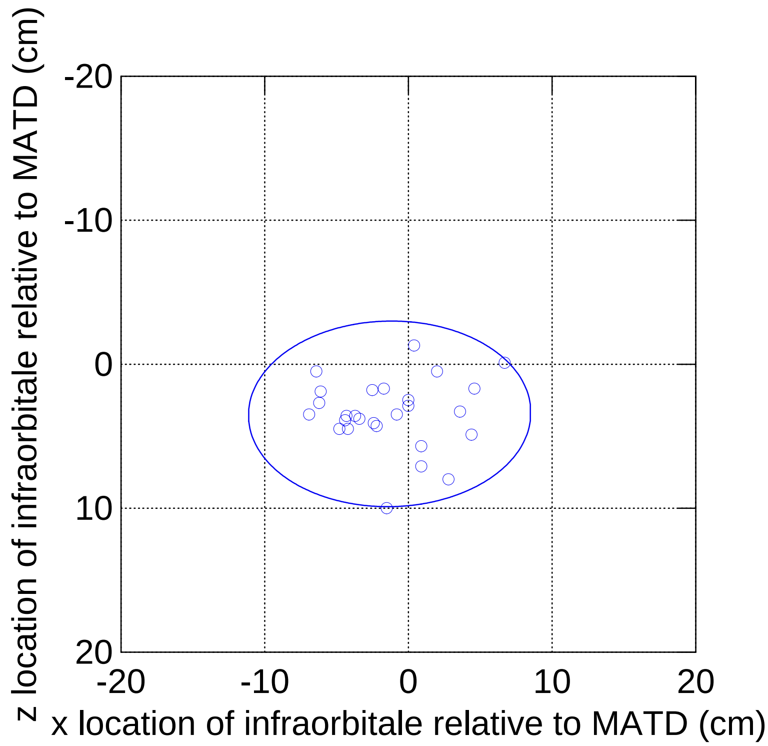

Figure 5. 95 percent confidence interval of x,z location of human subject infraorbitale relative to MATD when rider is in most comfortable riding position.

In addition to the evaluation of the location of the human subject infraorbitale relative to the MATD infraorbitale, a similar analysis was done for the shoulder joint as well as the ASIS located on the MATD. The shoulder joint was defined as the top of the bolt securing the upper arm to the torso, while the ASIS location was palpated directly on the MATD pelvis and marked on the external surface of the pelvis. The same sign convention used for the infraorbitale evaluation (i.e. ISO 13232) was used for the shoulder and ASIS evaluations.

Figure 6 illustrates the x,z location of the shoulder relative to MATD. As the data indicates, the MATD shoulder is approximately 8.4 cm above and 3.3 cm in the location of the human subjects. It is important to note that the point 0,0 is not within the 95% confidence interval which would suggest that the MATD shoulder is at the same location as the human subject shoulders.

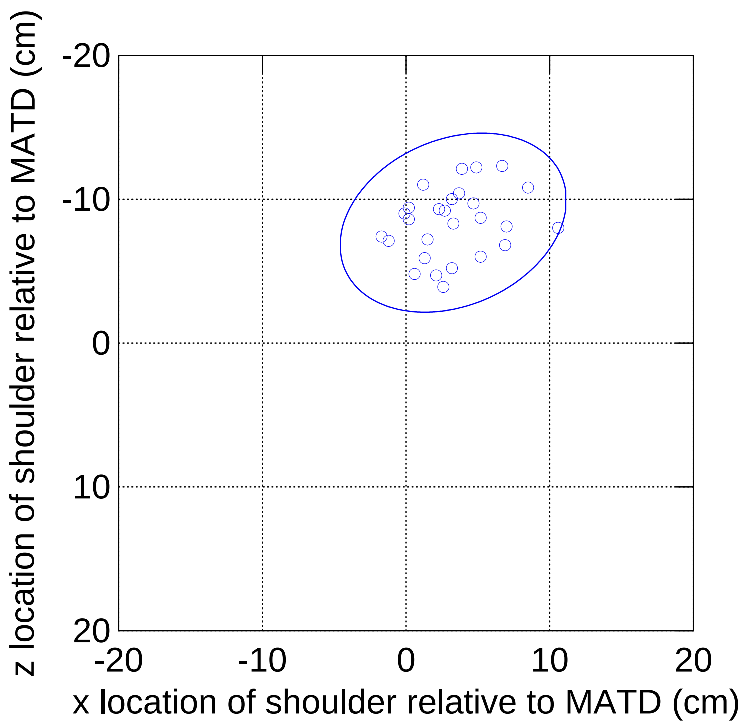

Figure 6. 95 percent confidence interval of x,z location of human subject shoulder relative to MATD when rider is in most comfortable riding position.

Along with the shoulder, comparisons were also made between the MATD ASIS and the human subject ASIS locations. Figure 7 illustrates the x,z location of the ASIS relative to MATD. The data shows a very good match between the MATD ASIS and the human subject. The mean difference between the MATD ASIS and the human subject ASIS measures is less than 2 cm in any direction.

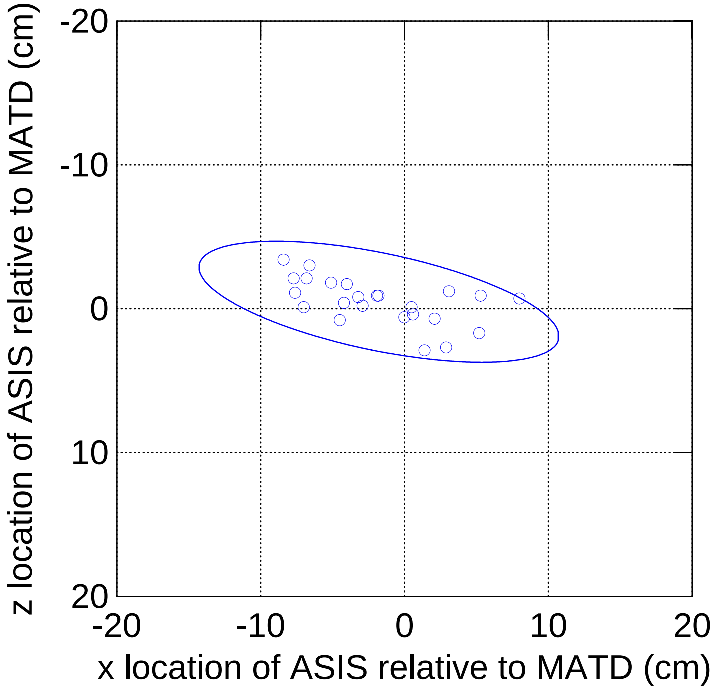

Figure 7. 95 percent confidence interval of x,z location of human subject ASIS relative to MATD when rider is in most comfortable riding position.

DISCUSSION

A total of nine subjects were selected for this project. It was intended that all subjects would fit within the 50th adult male height and weight ranges. In several cases the subject's weight was either above or below the target weight range of 73.6 to 80.5 kg. Since the subjects did meet the 50th percentile adult male height requirements (i.e. they were between 172.7 cm and 177.8 cm) and the major skeletal landmarks were used to ascertain segment lengths, body mass was not considered to be a major factor that would influence overall neck length.

The average neck length (i.e. C_7T_1 to occipital condyle) for all subjects across all trials was found to be 13.7 cm. This value agrees quite well with the work of Walker et al. (1973) wherein they reported a T_1 to external occipital protruberance distance of 13.4 cm.

This value is much higher than values previously published by McConville et al., 1980 as well as UMTRI, 1983, (i.e, 8.2 cm and 8.5 cm respectively). The difference between this study and the other two studies is primarily the position of the subject at the time of neck length measurement. During the McConville et al., 1980 study, the subject was in a standing posture while in the UMTRI study, neck length was measured for a reclined automobile driver. It is known that neck length changes as a function of torso angle and head position; and in a standard posture as well as in a reclined driving position, the cervical vertebrae are in their most retracted position, and thus the neck length is likely at a minimum in these particular positions. In comparison, operation of a motorcycle requires that the neck be extended and therefore, it is likely in a maximum length position, particularly when the rider is on a sport bike or in a forward leaning posture.

The primary objective of this study was to compare the current MATD ride height characteristics with a large group of 50^{th} percentile male motorcycle riders. This study found that rider neck length varied considerably as a function of rider posture, with the greatest neck lengths observed during the forward most riding postures.

It was not possible to make direct comparisons of MATD neck length to the human subject neck length, because there are no anatomical correlates on the MATD thorax and neck. In other words, there is no distinct physical location on the MATD which could be considered the cervicale, or C_7T_1 junction. Therefore, it was not possible to make direct comparisons between the human subject neck length and the MATD neck length.

In order to solve this problem, it was decided that the human subject tests defined as the most comfortable riding position would be compared to the ISO 13232 position of the MATD. Since there were no anatomical correlates, a visual overlay and measurement technique was used to determine if the MATD was located at the same height as the human subjects. The infraorbitale location was identified on both the human subjects and the MATD and this was used as the first indication of the neck length or upper torso length relative to the human subjects. A comparison between the MATD infraorbitale location and the human subjects indicated that the mean human subject infraorbitale was located in front of and below the current MATD position. This would suggest that the current MATD neck length might be greater than the neck length of a 50^{th} percentile male rider.

It is important to note that the 95% confidence interval of the MATD infraorbitale location does include the coordinates 0,0,0; therefore, statistically, the MATD infraorbitale is in the correct location and it is possible that the MATD neck may already be at an appropriate length for motorcycle crash testing.

In order to verify this, a comparison between the MATD shoulder joint and the human subject shoulder joint was made and this indicated that the MATD shoulder joint was over 8 cm below the shoulder joint of the human subjects. This suggested that the MATD thorax was much shorter relative to the thorax of a 50^{th} percentile human subject. As a result of this shorter thorax length, the neck of the MATD (e.g. the lower neck bracket and neck assembly) was longer. This could partially explain the visualization of a longer neck on the MATD.

Additional positional analysis revealed that the MATD thorax was found to be much shorter than the human subject thorax and therefore, some of the discrepancy between the human subjects and the MATD may be accounted for. In particular, the shoulders of the MATD were found to be well below the shoulders of the human subjects. While it is possible to introduce design changes which would move the shoulders closer to the human subjects, the effect that this would have upon MATD crash dynamics and dynamic response is not known at this time.

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