AN IMPROVED DUMMY NECK FOR THE ISO 13232 MOTORCYCLE ANTROPOMETRIC TEST DUMMY

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ABSTRACT

A new test dummy neck with improved biofidelity was developed specifically for motorcycle crash testing and is specified in the first revision of ISO 13232. This new neck has been approved to replace the modified Hybrid III neck originally specified for the Motorcyclist Anthropometric Test Device (MATD). The new neck was designed, with the aid of mathematical modeling, to address the unique posture and multi-directional biofidelity requirements of the MATD. It incorporates materials and features that are new to dummy neck design. It can be adjusted for a wide range of inclined torso angles that are associated with the large variety of motorcyclist riding postures. Biomechanical performance data for the new neck are presented that demonstrate characteristics in good agreement with various volunteer and cadaver test data. Additionally, an extensive series of high-energy tests have been conducted to evaluate the new design's reliability and repeatability.

BACKGROUND AND OBJECTIVES

International harmonization of test methodologies for the assessment of rider crash protective devices fitted to motorcycles was initiated in March of 1992. The aim was to resolve differences in methodologies used to evaluate the injury risks and benefits of potential protective devices. This harmonization process ultimately led to the development of International Standard 13232. This standard was approved and published in 1996 and has recently undergone a comprehensive review. Of particular significance to this paper are the changes to the dummy neck detailed in ISO/CD 13232-3 (2000).

A first prototype of the motorcycle anthropometric test dummy (MATD-1) was described by St-Laurent et al. [7] and later by Newman et al. [4]. It incorporated modifications to the Hybrid III dummy making it more suitable to the motorcycle impact environment and injury assessment needs. The head was modified to accommodate a motorcycle helmet and the standard Hybrid III neck was employed. Since the motion of the head was critical for the overall injury assessment of protective devices, the biofidelity of the neck was enhanced in the flexion-extension and torsional modes. The revised neck, and other dummy improvements, resulted in the MATD-2 which were detailed by Gibson et al. [2].

While improved neck biofidelity was obtained in these prototypes in the midsagittal plane under inertial loading conditions, analysis of the neck response in motorcycle impacts indicated that an overestimation of torsional moments was present with similar distortions for injury assessment. Exploratory research into the feasibility of motorcycle airbags also gave rise to concerns with head/helmet interactions [10] and the potential risk of airbag injury [6]. Improvements to the Hybrid III neck again ensued with improvements to the torsional biofidelity, frontal kinematics and force/moment relationships to achieve correct head position and phasing leading up to the interaction [3]. Additionally, the adjustment range of the head/neck was modified to accommodate the range of torso and head orientations across different motorcycle types to place the rider in a realistic position and the head in a realistic location and orientation relative to the airbag. Zellner et al. [11] presented an updated historical review of the dummy development and various neck modifications.

Recommendations for improved biofidelity and injury assessment methods resulting from experience with the neck for use in motorcycle airbag research [10,11] were approved by a committee resolution of ISO/TC22/SC12/WG5. These included specifications for frontal flexion/extension, force/moment and kinematic responses, lateral kinematic response consistent with ISO TR 9790, and torsional kinematic/moment response detailed in ISO/TC22/SC12/WG5 (N436). Newman et al. [5] also summarized the requirements and presented new neck concepts that were not based on the Hybrid III. The concepts could potentially meet the multi-directional response requirements while providing the effective foreshortening of the head to torso distance as the neck is flexed rearwards.

This was realized in a new neck design having compliant vertebral elements, a unique upper neck shear element, and mid-neck flexural adjustment as described by Withnall et al. [9]. Complete adjustment of the head angle was achieved at the mid-neck joint accommodating the full range of upright to forward leaning torso postures and allowing for realistic postures with different motorcycle styles. This neck substantially met the response requirements but required further reduction of torsional stiffness and lateral head excursion.

This paper describes changes made to this first design, performance results, and durability and repeatability studies conducted.

NECK GEOMETRY REQUIREMENTS

In designing a neck for a motorcyclist crash test dummy, the ability to position the torso and head in a realistic position and orientation is of paramount importance. This was achieved by first establishing the range of head and neck angles needed for a range of motorcycle types. One of the main differences between the motorcyclist riding position and that of the seated automotive driver is the angle of the torso. The automotive driver typically sits in a "slouched" posture with his torso leaning backward. The neck assumes a flexed position to keep the head comfortably level. In contrast, the motorcyclist typically sits in a forward leaning posture, with neck extended and head level. The rider may assume a wide range of inclined postures, depending on the type of bike and the riding style.

The location of the head relative to the torso for the automotive seating position is well established. However, similar information was not available for the unique postures of the motorcycle rider. To establish a relationship between the motorcyclist's extended neck angle and head position, a brief investigation was conducted. Three healthy adult males, nominally fiftieth percentile in height and weight, were seated on three different motorcycles including cruiser, commuter and sport styles. They were instructed to start with a comfortable riding position and then assume 5 to 6 progressively inclined postures while focusing on a marker in the horizon. Each posture was photographed in side view from approximately 15 m with a telephoto lens to minimize parallax error.

Transparent overlays of the Hybrid III thorax and head were scaled to match the photographs. Thoracic reference axes were aligned with the spine box / lower neck bracket interface, origin at the rear mounting bolt. Head reference axes were aligned with the Frankfort plane, origin at the occipital condyle pin. The overlays were positioned to match the subject torso and head locations, as shown in Figure 1, and the head/torso angle and (X,Z) coordinates were measured for each riding posture.

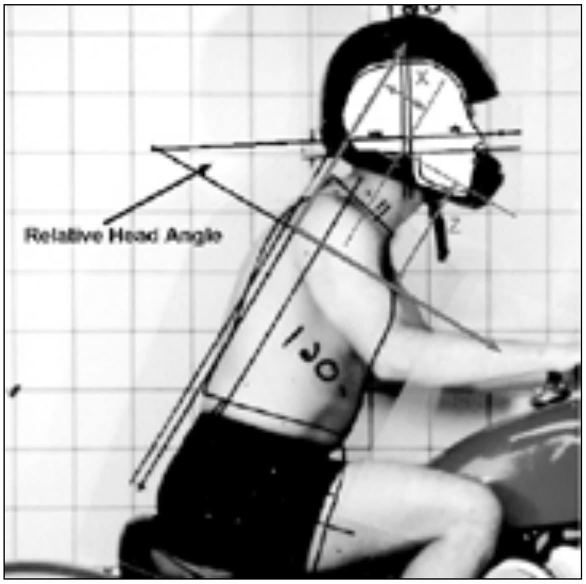

Figure 1. Subject on bike with Hybrid III torso and head overlays.

For the volunteers investigated, it was observed that the head remained substantially level throughout the range of inclined postures, except for extreme forward inclination over the fuel tank, where the neck could not be extended further. Relative head/torso angles ranged from 12 to 73 degrees. This compared favorably with the range of torso angles experienced previously in motorcycle crash testing, which were 15 to 65 degrees. This latter range became the design target for the new MATD neck.

As indicated in Figure 2, the occipital condyle location clearly followed a prescribed path for each subject regardless of motorcycle type. Furthermore, this path was reasonably linear and similar for all riders. The data from all three subjects were combined, and a linear regression curve was created for both the X and Z values versus head-torso angle, as shown in Figure 3. Using these regression equations, coordinates for the occipital condyles at torso angles of 15 and 65 degrees were determined, as shown in Table 1

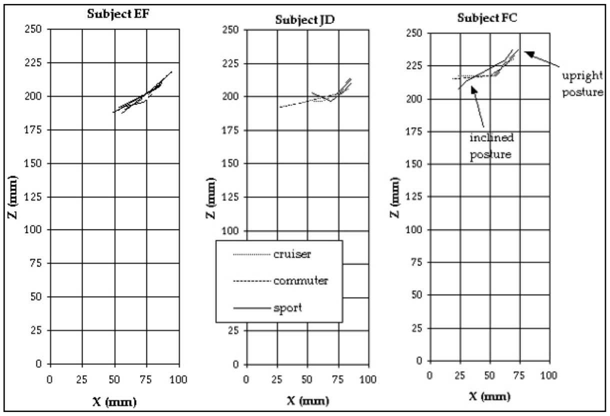

Figure 2. OC position relative to Hybrid III spine box upper plate.

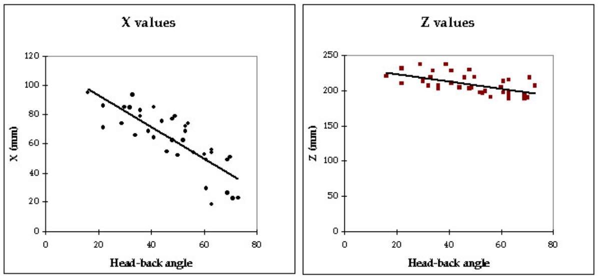

Figure 3. Linear regression of combined subject data.

Table 1.
Occipital condyle range

Torso angle (degrees)	X (mm)	Z (mm)
15	99	226
65	45	200

Having the angle of the head relative to the back and the co-ordinates of the OC at these positions, it was possible to determine a virtual pivot location. A zero degree angle was also needed for testing validation purposes, so this was simply taken as an extension of the arc from that virtual pivot. An outline of the eventual design is shown in Figure 4. In this figure, the base of the neck is kept level, while the head is extended at 15 and 65 degrees. The dimensions shown in this figure are based on Table 1, within a few millimeters.

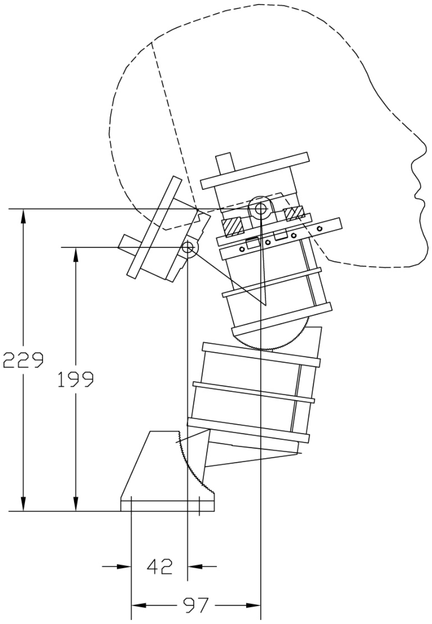

Figure 4. Head position at 15 and 65 degrees extension.

NECK DESIGN

General Overview

The MATD neck was redesigned as a departure from the original Hybrid III-based MATD neck. The major details of this design have been described previously [11]. However, there are three features unique to this design that are highlighted here. First, all of the head angle adjustment is accomplished via a spline-toothed joint at the mid-span of the neck. The base of the neck attaches to the existing Hybrid III lower neck bracket. This bracket is permanently set to 5.25 degrees of extension. Each tooth provides 2.5 degrees of adjustment, such that the technician attempting to set the head level will be out by no more than 1.25 degrees. Second, the four elastomeric urethane disks that allow neck bending are longer in the fore-aft direction than laterally to accommodate the unique bending stiffness requirements of frontal and lateral loading. They also become progressively larger towards the base of the neck to account for increased bending moment. Thirdly, and most unique, is the upper neck slider mechanism that allows 20 mm of forward translation of the head on the upper neck before significant neck bending occurs. This was developed via MADYMO modeling to mimic the "head-lag" phenomenon observed in Naval Biodynamics Lab volunteers [8]. A schematic of the neck's positioning range and slider mechanism are shown in Figure 5.

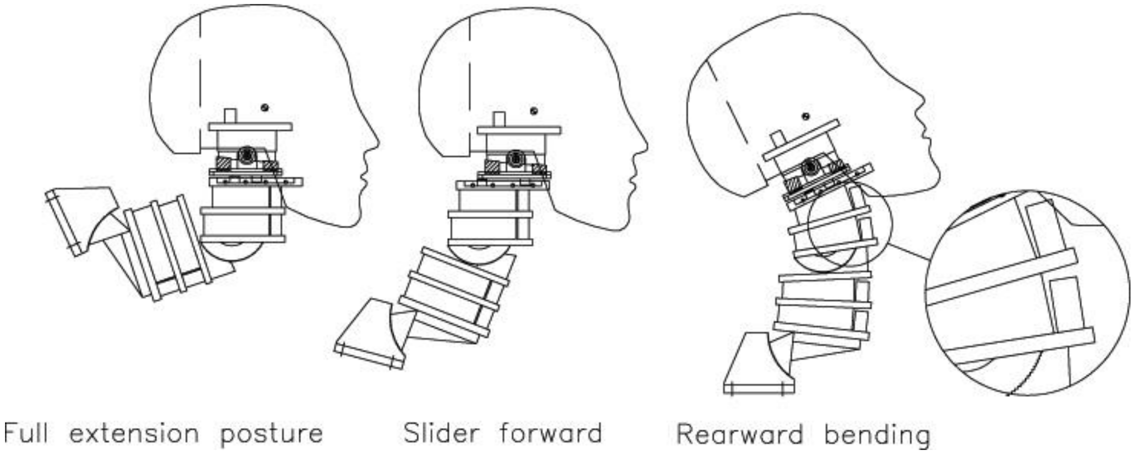

Figure 5. Neck adjustment, slider mechanism and segmented disks.

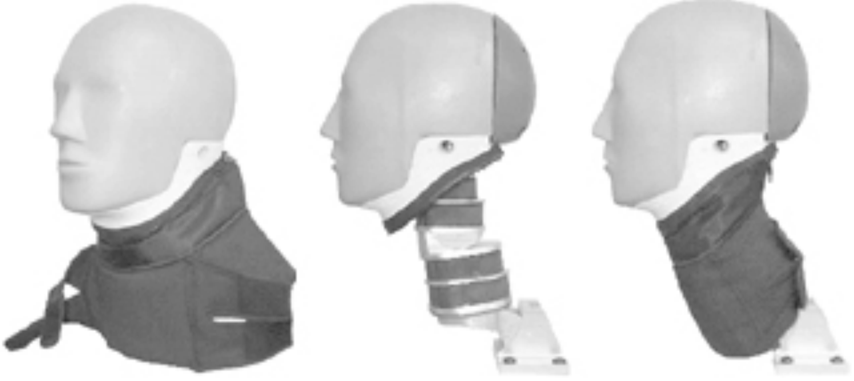

Figure 6. Neck shroud and head-skin extensions.

Neck Torsion

In original reporting [9], the performance of the neck was shown to be very good for the majority of loading directions with the exception of excessive torsional stiffness. Unfortunately, the need for the vertebral disks to satisfy both the fore-aft and lateral bending requirements precluded any reduction in disk size to soften the neck in torsion. To remedy this, each elastomeric disk was divided into front and rear portions. The larger rear portion was firmly bonded top and bottom to thin aluminum dividing plates. The smaller front portion was only bonded to the lower aluminum plate. In this way, neck extension and neck twist are controlled by the rear elastomeric disks, while in frontal flexion the front disk portion contributes to the overall stiffness.

Neck Shroud

Each disk was redesigned using a stiffer urethane of smaller cross-section than the original MATD design. This was done to minimize the strain in each disk at full bending. This more slender neck also made necessary a shroud covering to bring the outer neck shape closer to that of a human. It was also necessary to fill the hole under the Hybrid III chin when experimenting with airbag systems on motorcycles. This neck shroud connects to the underside of the Hybrid III jaw extensions [2] by a zipper. Elastic fabric tabs with Velcro™ closures extend around to the rear of the neck holding down a frontal padded flap. This allows the shroud to be effective even at highly extended initial neck angles. An illustration of the neck shroud is shown in Figure 6.

NECK BIOFIDELITY REQUIREMENTS AND PERFORMANCE

The MATD neck performance targets have been described in detail elsewhere [9] but are summarized in Table 2. Illustrations of these performance targets will follow in relation to the new neck design performance response. A standard Hybrid III was tested simultaneously for comparison. Flexion, extension and lateral flexion testing were conducted on a HyGe sled. The sled pulses for frontal and lateral flexion were controlled by a specialized HyGe pin to simulate the acceleration pulse at the base of the neck of NBDL volunteers [9]. The sled accelerations and velocity changes are shown in Table 3.

Table 2.
Neck biofidelity criteria

Loading Direction	Performance Target
Flexion	Mertz modified moment-angle corridors (Newman et.al.1996) Thunnissen et al. (1995) head-neck angle relationship Thunnissen et al. (1995) CG and OC position relationship
Lateral Flexion	ISO TC22/SC12/WG5/N455 (1997) CG maximum trajectory ISO TC22/SC12/WG5/N455 (1997) peak lateral head angle
Extension	Mertz modified moment-angle corridors (Newman et.al.1996)
Torsion	ISO/DIS 13232-3 (1995) torque-angle relationship

Table 3.
Sled test pulse characteristics

Loading Direction	Test No.	Target peak accel. (G)	Target velocity change (m/s)	Actual peak accel. (G)	Actual velocity change (m/s)
Extension	3371	6	4.5	5.57	4.53
	3372	6	4.5	6.11	4.7
Lateral flexion	3373	13	7.7	13.37	5.85
	3374	13	7.7	13.24	7.69
Frontal flexion	3375	23	17	23.71	16.85
	3376	23	17	23.71	16.75

Extension

The extension torque-angle response of the new MATD neck prototype and standard Hybrid III are shown in Figure 7. The results show that the MATD undergoes 58 degrees of head rotation compared to 46 degrees for the Hybrid III. It falls outside the corridor briefly at about 50 degrees of head rotation, but for the most part remains within the target corridor. The Hybrid III curve stays within the corridor for the entire loading phase.

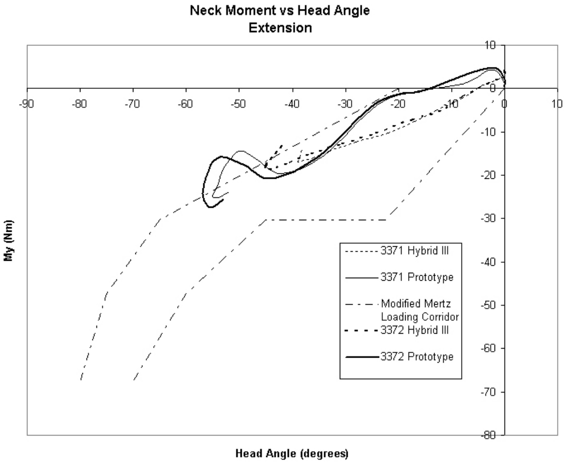

Figure 7. Extension response.

Lateral Flexion

The lateral flexion center of gravity trajectory is shown in Figure 8 relative to the ISO peak excursion window. The results show that the MATD prototype places the head in the correct position at peak displacement, while the Hybrid III does not.

The lateral flexion head angle response is shown in Figure 9 relative to the ISO minimum-maximum corridor. The results show that the MATD prototype exceeded the peak head angle by approximately 10 degrees, while the Hybrid III is less than half of the minimum rotation.

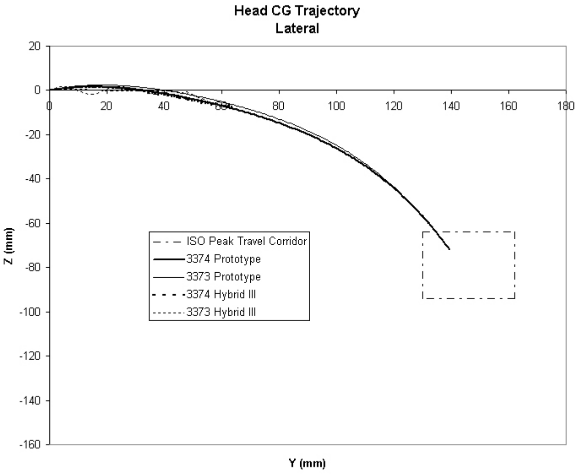

Figure 8. Lateral flexion CG trajectory.

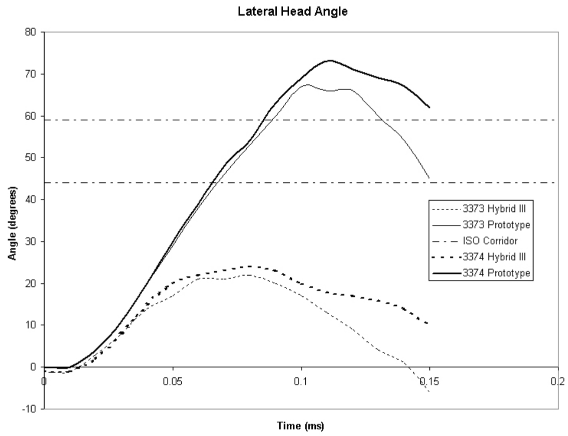

Figure 9. Lateral flexion head angle response.

Frontal Flexion

The flexion moment-angle responses of the MATD and Hybrid III are shown in Figure 10. The results show that the new MATD prototype exhibits some rearward head motion at the onset, owing to more initial head translation and a longer travel. The varied response of both necks is owing to the unique sled pulse used in the NBDL volunteer neck study. The trajectories of the occipital condyle (OC) and head center of gravity (CG) are shown in Figure 11. The results show that the prototype neck remains substantially within the corridor and displays a human-like range of motion, but the Hybrid III falls outside and displays only about one-half of the human-like motion. The relationship of change in neck angle versus change in head angle is shown in Figure 12. The prototype neck is shown to demonstrate a human-like head-lag behavior, which approaches the corridor, but does not fall in it. It still remains substantially more human-like than the Hybrid III. The Hybrid III displays no head-lag and limited rotation.

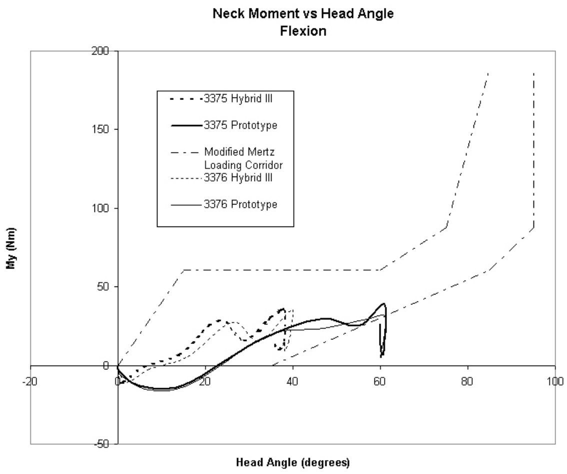

Figure 10. Flexion response.

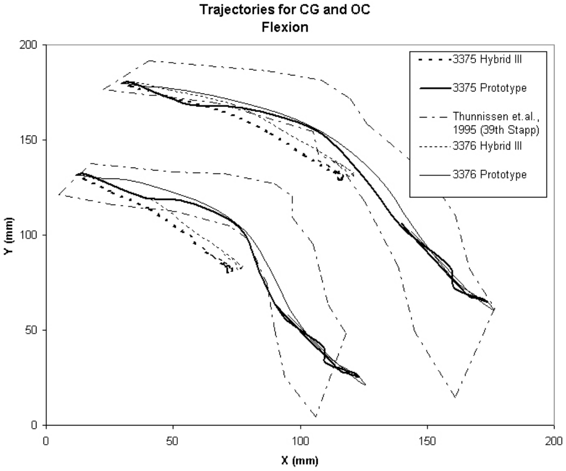

Figure 11. Flexion OC and CG trajectories.

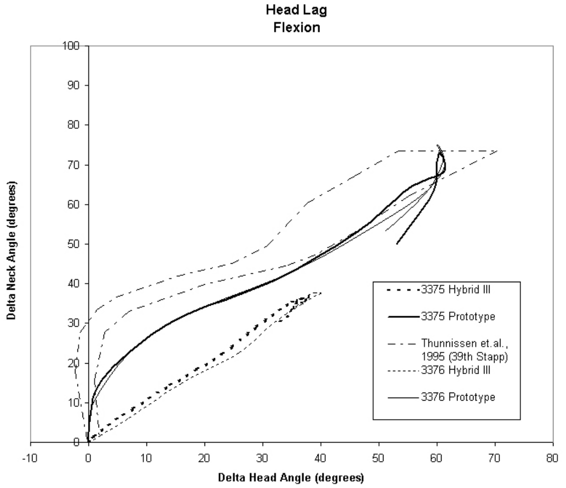

Figure 12. Flexion head lag.

A more recent analysis of the NBDL data [1] revealed a less pronounced head lag and a more arc-shaped trajectory for the head center of gravity. The head center of gravity trajectories for the MATD and Hybrid III necks are shown in Figure 13 relative to the new corridor. The results show that the center of gravity trajectories for both necks fall within the corridor, with the Hybrid III following the bottom boundary and the MATD prototype following the upper boundary. In Figure 14 the head-lag response is shown against the new corridor where the MATD prototype demonstrates excellent head-lag response, but later undergoes slightly excessive head rotation. The Hybrid III again exhibits no head-lag behavior and limited rotations.

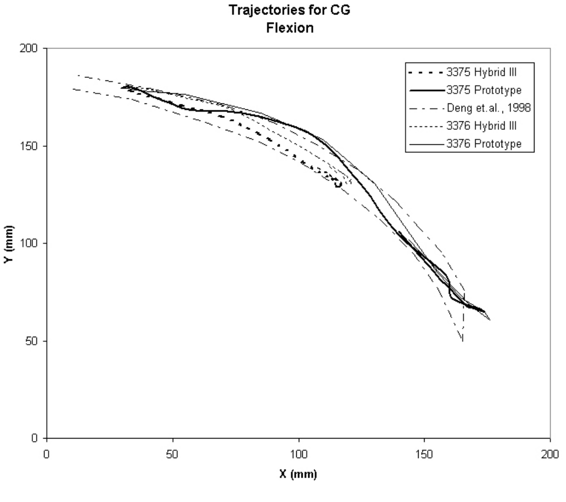

Figure 13. Re-analyzed flexion CG trajectory.

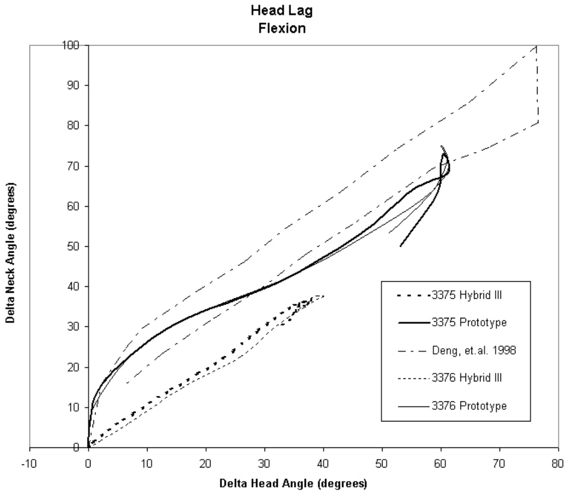

Figure 14. Re-analyzed flexion head lag.

NECK PRACTICALITY REQUIREMENTS

In addition to the neck performance requirements, practical considerations must be addressed to assure confidence in the results from test to test, and to ensure that the neck is suitable for the test environment and users of the neck. The considerations of impact dummy components include:

- Calibration
- Ease of manufacturing
- Conformity of production
- Certification
- Durability
- Ease of installation and adjustment
- Repair and replacement

Calibration of the neck was based on simple static deflection measurements at specified force and moment levels. A static procedure was considered to be more practical and feasible in the field than the relatively complex dynamic sled tests used to develop the neck. This procedure was standardized as part of the committee draft first revision of ISO 13232.

In order to address ease of manufacturing, conformity of production and certification, two performance verification procedures were developed. For initial conformity of production for a given neck design, material specification, and manufacturing process, the full dynamic sled test battery and associated dynamic measurements previously described is required. For subsequent conformity of production, measurement using the static calibration procedure is specified. Both of these were standardized as part of the committee draft first revision of ISO 13232. The requirements for subsequent conformity of production are provided in Table 5, along with the test results of the original neck and the first three copies manufactured.

In order to assess the practicality and durability of the new neck in a 30 mph (48 km/h) impact into the side of a car (ISO impact configuration 413-0/30), a full-scale test (FST) was conducted at JARI. Copy 1 of the new MATD neck was mounted to an ISO 13232 motorcyclist dummy which was positioned on a Kawasaki GPZ 500 motorcycle equipped with a UKDS leg protector. This test configuration was chosen because previous testing with the initial ISO 13232 neck, the Kawasaki GPZ 500 and UKDS leg protector, and this impact configuration resulted in a direct impact between the helmet and the side of the opposing vehicle, which produced very large neck loads. The primary impact period (0-500 ms) neck loads for the two different necks are shown for comparison in Table 6.

For this motorcycle frontal impact the primary measures were Fx, Fz, and My. The data indicate that using the new, more flexible and human-like neck resulted in reduced Fx, Fz, and My loads. An inspection of the new neck after the FST showed no visible damage to the neck..

Regarding ease of installation and adjustment, during the pre-test set up the new neck was found to be easy to work with. The neck shroud was easy to install and the neck angle adjustment allowed the head angle to be set at 0 degrees which was not possible with the previous MATD neck on this motorcycle configuration, requiring a 28 degree torso angle.

After the FST, the Copy 1 neck was assembled with a Hybrid III head and upper neck load cell and tested for durability. The neck was subjected to a series of dynamic bending tests using a Part 572 neck test pendulum. The drop heights (measured by pendulum arm angle) and pendulum deceleration rates were chosen to produce neck moments which were equivalent to those experienced in severe crash tests, as shown in Table 4.

Table 4.
Neck moments produced by pendulum tests.

Primary motion	Flexion	Extension	Lateral flexion
Peak torque (Nm)	90-110	70-85	40-50
Arm angle (deg)	120	90	90

The test process involved subjecting the neck to about 15 pendulum tests followed by a physical inspection for damage and a check of the neck deflection characteristics using the subsequent conformity of production test procedures. This process was repeated until the neck had been subjected to 100 pendulum tests. The results shown below in Table 7 indicate that the neck continued to meet all static deflection criteria.

After the 24th pendulum test a small (6 mm) crack was observed on the back of the second disk from the top of the neck. Testing continued with careful examination of the crack after each test. The crack grew incrementally to a length of about 10 mm. After sixty (60) pendulum tests the crack was repaired using a cyanoacrylate adhesive. This closed the majority of the crack until testing was stopped after 100 tests.

Table 5
ISO subsequent conformity of production requirements and production test results.

	Average flexion angle (deg)	Average slider displacement (mm)	Average extension angle (deg)	Average lateral bending angle (deg)	Average torsion angle (deg)
ISO 13232-3 requirements	17.6 ± 2.6	14.0 ± 3.0	30.9 ± 4.6	28.7 ± 4.3	41.5 ± 6.2
Original neck	17.5	13.0	30.9	28.7	41.5
Copy 1	16.3	12.4	27.7	26.4	37.9
Copy 2	17.1	12.2	28.5	26.3	36.9
Copy 3	18.0	14.7	29.7	27.1	38.2

Table 6
Neck full scale test loads comparison.

MATD	Fx (kN)		Fy (kN)		Fz (kN)		Mx (Nm)		My (Nm)		Mz (Nm)	
	+	-	+	-	+	-	+	-	+	-	+	-
Old	4.02	-1.32	0.59	-0.09	1.81	-5.57	27.06	-15.74	62.19	-87.71	34.51	-4.50
New	0.53	-1.48	0.30	-0.22	1.58	-1.29	10.47	-33.21	23.45	-67.78	16.77	-14.20

Table 7
Durability testing of Copy 1 to subsequent conformity of production test methology.

Sequence of test	Average flexion angle (deg)	Average slider displacement (cm)	Average extension angle (deg)	Average lateral bending angle (deg)	Average torsion angle (deg)
Original calibration	16.3	12.4	27.7	26.4	37.9
After FST	15.5	13.0	27.5	26.4	37.9
After 7 E, 10 F, 0 L *	17.7	15.3	30.7	29.4	41.1
After 14 E, 10 F, 0 L	16.9	15.5	29.8	28.7	39.8
After 16 E, 16 F, 0 L	18.1	16.3	31.6	30.0	41.3
After 23 E, 23 F, 0 L	18.3	16.3	31.0	30.2	41.3
After 30 E, 30 F, 0 L	18.4	17.3	31.7	30.4	41.8
After 30 E, 30 F, 10 L	17.8	16.9	30.9	31.1	41.6
After 30 E, 30 F, 25 L	17.8	17.2	31.1	31.5	41.5
After 30 E, 30 F, 40 L	18.1	17.0	31.0	31.9	41.9

*Note: 7 E, 10 F, 0 L, indicates 7 extension, 10 flexion and 0 lateral pendulum tests

The durability test results of Copy 1 show that the neck met the flexion, extension, lateral, and torsion specifications throughout the entire test series. This included testing while the small crack existed. The slider displacement requirement (14 ± 3 mm) was met until after 60 tests.

With regard to repair and replacement, periodic calibration tests indicated that the slider spring had the shortest life, the cost of replacing the slider spring would be low and spare slider springs could be purchased, kept with the dummy and replaced in the field if needed. In addition it is noted that if necessary, a single urethane disk could be replaced for much less than the cost of a new neck.

It is conceivable that due to aging and use, the dynamic characteristics of the neck might change without changes in the static characteristics. It was noted by WG22 and stated in the first draft revision of 13232 that users should check necks for age and use-related changes in dynamic properties and report any relevant findings to WG22.

Based on this series of tests it is concluded that the new neck design:

- can be manufactured in a repeatable manner,
- can be successfully used in full scale tests,
- includes adequate angle adjustment to properly orient the head,
- is not critically affected by small cracks,
- continues to meet calibration specifications until after about 60 severe impacts, and
- can be field repaired if small cracks occur.

When considering the demonstrated service life of the neck and the low cost of replacing or repairing urethane parts as needed, the life cycle cost of the new neck is expected to be somewhat less than that of the previous MATD neck design.

CONCLUSION

The need for a new multi-directional motorcyclist dummy neck and neck injury assessment method was identified during previous research studies with protective devices, in particular with airbags. Previous neck designs were able to provide some frontal and lateral biofidelity but lacked the necessary lateral and torsional response required for the assessment of airbag-induced loads. They were also unable to provide injury predictions representative of real world accident data. A new neck was developed which satisfactorily meets these needs.

Compared to the standard Hybrid III neck, the new prototype demonstrates a more compliant structure with greater dynamic displacement that is consistent with volunteer biomechanical data. Some small divergences from kinematic corridors were observed but such corridors would be difficult to meet simultaneously and uniformly without the use of external cables or linkages to further control neck motion. However, this approach of using cables may not be suitable for use with a multi-directional neck design subject to diverse impacts and could prove problematic upon direct contact with airbags or car roof structures.

With the new neck the excursion of the CG in lateral bending was good, but the allowable head rotation was exceeded. This highlights a possible contradiction in these two requirements, since it does not appear to be possible to meet both simultaneously without external controls.

The torsional moment response has been substantially improved over earlier designs. Although even better torsional response is desirable, compromises to the frontal and lateral bending performance would be likely, thus further design changes are not anticipated. The new design also provides the ability to change the torso and head orientation to represent typical riding postures across a range of motorcycle styles and is more suitable for airbag performance assessment than previously possible.

Overall, the new neck design has demonstrated to be a practical, repeatable, and robust tool for injury assessment in the motorcycle impact environment.

REFERENCES

[1] Deng, B., Melvin, J.W., Rouhana, S.W., “Head-Neck Kinematics in Dynamic Forward Flexion”, proceedings from the 42nd Stapp Car Crash Conference, SAE paper no. 983156, 1998, pp. 179-193.

[2] Gibson, T.J., Newman, J.A., Zellner, J.W., Wiley, K.D., “An Improved Anthropometric Test Device”, Proceedings of the NATO Advisory Group for Aerospace Research and Development Conference, Cesme, Turkey, AGARD, France, 1992, pp. 19-1 to 19-7.

[3] Gibson, T., Shewchenko, N., Withnall, C., ”Biofidelity Improvements to the Hybrid III Neck”, proceedings of the 14th International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, National Highway Traffic Safety Administration, Washington DC, 1994, pp. 159-168.

[4] Newman, J.A., Zellner, J.W., Wiley, K.D., “A Motorcyclist Anthropometric Test Device MATD”, proceedings of the International IRCOBI Conference on the Biomechanics of Impacts, IRCOBI, France, 1991, pp. 285-293.

[5] Newman, J., Withnall, C., Gibson, T., Rogers, N., Zellner, J.W., ”Performance Specifications for the Neck of a Motorcycle Anthropometric Test Dummy”, proceedings of the 15th International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia, National Highway Traffic Safety Administration, Washington DC, 1996, pp. 1679-1689.

[6] Ramet, M., Bourquet, R., Bouallegue, M., Bermond, F., Cesari, D., “The Effect of Air Bag Inflation on the Cinematic and the Lesions of a Motorcyclist”, proceedings of the 14th International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, National Highway Traffic Safety Administration, Washington DC, 1994, pp. 1241-1246.

[7] St Laurent, A., Szabo, T., Shewchenko, N., Newman, J.A., “Design of a Motorcyclist Anthropometric Test Device”, proceedings of the Twelfth International Conference on Experimental Safety Vehicles, Göteborg, Sweden, National Highway Traffic Safety Administration, Washington DC, 1989, pp. 1308-1316.

[8] Thunnissen, J., Wismans, J., Ewing, C.L., Thomas, D.J., “Human Volunteer Head-Neck Response in Frontal Flexion: A New Analysis”, proceedings from the 39th Stapp Car Crash Conference, SAE paper number 952721, 1995, pp. 439-460.

[9] Withnall, C., Fournier, E., “A New Neck for Motorcycle Crash Testing”, proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, Canada, National Highway Traffic Safety Administration, Washington DC, 1998, pp. 2375-2383.

[10] Zellner, J.W., Newman, J.A., Rogers, N.M., “ Preliminary Research into the Feasibility of Motorcycle Airbag Systems”, proceedings of the 14th International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, National Highway Traffic Safety Administration, Washington DC, 1994, pp. 1198-1210.

[11] Zellner, J.W., Wiley K.D., Broen, N.L., Newman, J.A., “ A Standardized Motorcyclist Impact Dummy for Protective Device Research”, proceedings of the 15th International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia, National Highway Traffic Safety Administration, Washington DC, 1996, pp. 1756-1781.