SCALING OF NECK PERFORMANCE REQUIREMENTS IN SIDE IMPACTS

Jac Wismans*, Riske Meijer*, Carmen Rodarius*, Bernard Been **
*** TNO Science and Industry, Helmond. The Netherlands**
**** First Technology Safety Systems (FTSS), Delft. The Netherlands**

ABSTRACT

Neck biofidelity performance requirements for different sized crash dummies and human body computer models are usually based on scaling of performance requirements derived for a 50th percentile body size. The objective of this study is to investigate the validity of the currently used scaling laws for the human neck in case of side impacts. Based on an analysis of human volunteer tests carried out by the Naval Biodynamics Laboratory in New Orleans, new criteria are presented deviating from the criteria resulting from geometrical scaling laws as proposed by Irwin *et al.* (2002).

Keywords*:* ANTHROPOMETRY, DUMMIES, SIDE IMPACTS, MODELS, VOLUNTEERS

THE HEAD-NECK BIOFIDELITY of side impact dummies can be assessed according to the response requirements for the head-neck system based on midsize male human subjects as published in ISO TR9790 (1999). These criteria are largely based on volunteer tests performed at the Naval Biodynamics Laboratory in New Orleans (NBDL) (Wismans *et al.*, 1986).

Since there are no side impact tests available of small female human subjects, the head-neck response requirements for a small female dummy are usually scaled from those of the midsize male dummy. The scaling can be done using the scaling rules of Irwin *et al.* (2002). The scaling procedures of Irwin assume that the human neck behaves more or less like an elastic beam. But due to the large flexibility of the neck, particular if muscular activity is limited, this assumption can be questioned.

In this study an analysis of a number of the NBDL tests has been carried out in order to study the influence of body size on the actual head-neck performance of the volunteers. On the basis of this new biofidelity criteria have been developed for the 5th percentile female and the resulting criteria have been compared with scaling based performance criteria developed by Irwin *et al.* (2002).

IRWIN'S SCALING METHOD

Irwin *et al.* (2002) developed a method to scale the ISO TR9709 lateral impact response requirements from midsize male to other size dummies. The various scale factors related to anthropometry as developed by Irwin for the 5th percentile female are presented in Table 1. The various scale factors related to the biofidelity criteria based on the NBDL tests are also included in this table. To calculate the scale factors for the peak head flexion angle, peak lateral displacement, time of maximum lateral displacement and the peak accelerations, the neck was assumed to behave like a cantilever beam with a point mass on the free end. Using this model, the response scale factors could be derived from energy balance store in the neck at maximum flexion (the head's kinetic energy is converted to elastic energy in the neck). To derive the scale factor for the peak twist angle, the head-neck system was modelled as a cylindrical shaped beam with a point mass on the free end rotating around its length axis. The twist angle could be derived from the energy balance store in the neck at maximum twist.

The resulting response requirements for ISO TR9790 for small female dummies in these tests as developed by Irwin *et al.* (2002) are given in Table 3.

ANALYSIS OF NBDL DATA

The Naval Biodynamics Laboratory in New Orleans (NBDL) has conducted a large number of human volunteer tests in various impact directions. A number of the lateral impact tests have been analyzed here in order to investigate the possible relationship between head-neck anthropometric parameters and the actual performance in a dynamic test.

Table 1. Scale factors for length, mass, mass moment of inertia and stiffness (left) for the small female relative to the midsize male and scale factors for the ISO TR9790 NBDL based requirements (right) according to Irwin *et al.* (2002).

Anthrop. scale factors	Factor	Biofidelity scale factors	Factor
Head mass	0.810	Sled velocity	1
Head length	0.932	T1 lateral acceleration	1.224
Head inertia	0.704	T1 lateral displacement	0.817
Neck mass	0.501	Neck lateral flexion angle	1.272
Neck length	0.794	Neck twist angle	1.272
Neck bending stiffness	0.794	Head lateral acceleration	0.990
Neck torsional stiffness	0.501	Head lateral displacement	0.808
Torso length	0.895	Time peak head lat. disp.	1.010
Torso stiffness	0.895	Head vertical acceleration	1.259
Total body mass	0.597	Head vert. displacement	0.590

The peak head response values as function of initial neck length (defined as the distance between the T1 and head anatomical origin) are plotted in Fig. 1. These peak response values were taken from the lateral sled tests conducted at 7.2 G, since the ISO TR9790 head-neck response requirements were derived from these tests.

Regression analysis was used to find relations between these anthropometry parameters and the head responses. The straight lines in the figures are the least squared functions resulting from this linear regression analysis. The coefficient of determination (R^2) and the correlation coefficient (ρ) were used to define the accuracy of the regression models. In this study it is assumed that if both R^2 and ρ are larger than 0.5 a linear relation is likely. As is clear from Fig. 1a and Fig. 1b, a relation between the initial neck length with the peak head lateral flexion angle (R^2 = 0.05, ρ = 0.22) and with the peak head twist angle (R^2 = 0.00, ρ = 0.04) is not really present. From Fig. 1 c and d it can be seen that a positive correlation between the initial neck length with the peak lateral displacement (R^2 = 0.77, ρ = 0.88) and with peak vertical displacement (R^2 = 0.55, ρ = 0.74) does exist.

In a similar way also the peak head response values as function of head mass in the 7.2 G NBDL lateral impact tests were investigated. The subject's head mass has been estimated based on measured head geometry data and using the regression equations proposed by McConville *et al.* (1980). From the regression analyses, no relation was found between the head mass with the peak head flexion angle (R^2 = 0.31, ρ = 0.51), peak head twist angle (R^2 = 0.00, ρ = -0.06), peak head lateral displacement (R^2 = 0.15, ρ = 0.39), peak head vertical displacement (R^2 = 0.03, ρ = 0.17).

Irwin *et al.* (2002) assumed that the neck bends like a cantilever beam. From the NBDL volunteer analysis it follows however that the head flexion angle and the head twist are not related to the neck length so that the cantilever beam model is found not to be a good approximation for the head kinematics in the NBDL tests. From the NBDL volunteer analysis it can be further seen that the head kinematics (lateral flexion, head twist, lateral and vertical displacements) are not related to the head mass.

Wismans and Spenny (1983) were able to describe the head motion well using a model of 2 pivots, one located in the torso near T1, with the rotation axis perpendicular to the impact plane and one located near the occipital condyles rotating about the axis perpendicular to the impact plane and rotating about the axis parallel to the head anatomical z-axis. Taking in mind that the peak head lateral and vertical displacements were found to depend on the neck length and most of the volunteers have an almost similar head flexion and twist, the model has been used in our study for scaling the neck requirements from midsize male to small female.

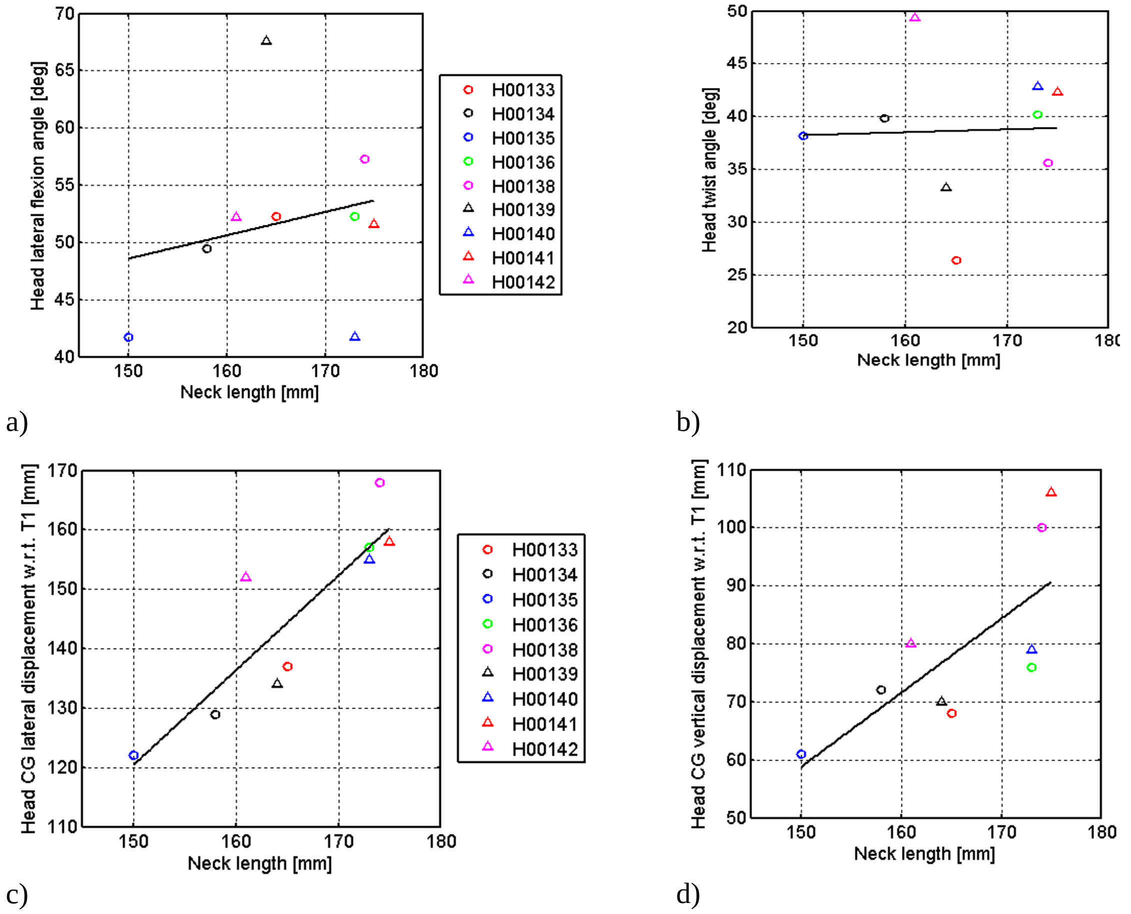

Fig. 1 - Peak lateral head flexion angle (a), peak head twist angle (b), peak lateral head displacement (c), and peak vertical head displacement (d) as function of initial neck length.

The head dynamics and time of the peak head lateral displacement of the small female are scaled taking into account the scaling method for the kinematics as described above. The scale factors according to the new method for the length, mass, mass moment of inertia and stiffness of the head and neck are given in Table 2. The new scale factors to scale the requirements of ISO TR9790 NBDL neck test for the midsize male to small female are also given in this table.

Table 2. Scale factors for length, mass, mass moment of inertia and stiffness (left) for the small female relative to the midsize male and scale factors developed in this study.

Anthrop. scale factors	Factor	Biofidelity scale factors	Factor
Head mass	0.810	Sled velocity	1
Head length	0.932	T1 lateral acceleration	1
Head inertia	0.704	T1 lateral displacement	0.817
Neck mass	0.501	Neck lateral flexion angle	1
Neck length	0.895	Neck twist angle	1
Neck bending stiffness	0.810	Head lateral acceleration	1.117
Neck torsional stiffness	0.810	Head lateral displacement	0.895
Torso length	0.895	Time peak head lat. disp.	0.895
Torso stiffness	0.895	Head vertical acceleration	1.117
Total body mass	0.597*	Head vertical displacement	0.895

The corridor specifications of the ISO TR9790 NBDL neck test were scaled according to these new scale factors and are given in Table 3. The corridor widths for small female were assumed to be relatively the same as for the midsize male, as was assumed by Irwin *et al.* (2002).

Table 3. ISO TR9790 NBDL neck test requirements for the midsize male, the small female requirements scaled according to Irwin *et al.* (2002), and the new small female requirements.

	Requirements 50th male		**Requirements 5th female Irwin *et al.* (2002)**		**Requirements 5th female New**	
Response	Lower	Upper	Lower	Upper	Lower	Upper
Peak horizontal acceleration of T1 [G]	12	18	15	22	12	18
Peak horizontal displacement of T1 rel. sled [mm]	46	63	38	51	38	51
Peak horizontal displacement of head CG rel. T1 [mm]	130	162	121	151	116	145
Peak vertical displacement of head CG rel. T1 [mm]	64	94	80	118	57	84
Time of peak head excursion [s]	0.159	0.175	0.161	0.177	0.142	0.157
Peak lateral acceleration of head [G]	8	11	8	11	9	12
Peak vertical acceleration of head [G]	8	10	10	13	9	11
Peak flexion angle [deg]	44	59	56	75	44	59
Peak twist angle [deg]	32	45	41	57	32	45

CONCLUSIONS

The most important differences between the new method for scaling the midsize male neck NBDL test requirements to small female and the scaling method of Irwin *et al.* (2002) is that the peak head displacements, flexion angle, and accelerations are determined using a simple linkage system. In this model the passive neck strength is proportional to the head mass resulting in similar peak flexion angles for small female as for male, and the peak head displacements scale with the neck length. In Irwin's study they were derived from the energy balance store in the neck at maximum flexion, with the neck modelled as a cantilever beam with a point mass on the free end.

References

Irwin A.L., Mertz H.J., Ali M. Elhagediab A.M. and Moss S. (2002): *Guidelines for Assessing the Biofidelity of Side Impact Dummies of Various Sizes and Ages*. Stapp Car Crash Journal, Vol. 46, paper No. 2002-22-0016, pp. 297-319.

ISO Technical Report 9790 (1999): *Road vehicles –anthropometric side impact dummy-Lateral response requirements to assess the biofidelity of the dummy.* ISO/TC22/SC12/WG5 Document N455 – Final edition.

McConville J.T., Churchill T.D., Kaleps I., Clauser C.E., Cuzzi J. (1980): *Anthropometric relationships of body and body segment moments of inertia*. Report AFAMRL-TR-80-119. Airforce Aerospace Medical Research Lab. Wright Patterson Airforce Base, Ohio.

Wismans J. and Spenny C. H. (1983): *Performance requirements for mechanical necks in lateral flexion.* Proceedings of the 27th Stapp Car Crash Conference, paper No. 831613, pp 137-148.

Wismans J., Van Oorschot H. and Woltring J. H. (1986): *Omni-directional head-neck response.* Proceedings of the 30th Stapp Car Crash Conference, paper No. 861893, pp. 313-331.