A Model of a Wheelchair Head Restraint to Reduce the Risk of Whiplash

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I. INTRODUCTION

The number of wheelchair users who remain in their wheelchairs during vehicular transportation is increasing, and it is important for those who travel in this way to receive the same level of safety as those who travel in commercial vehicle seats. Research into wheelchair safety for frontal collisions has led to various voluntary standards (e.g. ISO 7176-19) which have resulted in significant design changes for wheelchairs used in transit. However, although a standard for rear impact protection is in development and best practice guidelines are available; there is no particular requirement to provide a head restraint for rear impact protection for wheelchair users. Whiplash injuries can occur as a result of rear-end collisions caused by the relative motion between the head and torso. This relative motion can be generally reduced by the presence of a head restraint.

Previously [1] developed an experimentally validated MADYMO model of a 50th percentile male occupant (represented by a 50th percentile Hybrid III dummy) seated in a manual wheelchair and subjected by a 14g rear-end impact pulse. The model did not include a head restraint and the seatback uprights did not rotate. In this paper, the MADYMO model presented in [1] has been improved to better represent seatback deformation and a parameterised model of a head restraint was added to assess which design parameters are most influential for neck injury prevention during wheelchair rear impact.

II. METHODS

Additional degrees of freedom were provided to the model of the wheelchair seatback to facilitate inward deformation (towards the centre line of the wheelchair) of the structural upright components, as well as a more detailed representation of the canvas seatback deformation, see Figure 1. The model validity was assessed visually, graphically and statistically by comparing the results with the experimental sled test reported in [1].

A multibody head restraint model was developed and five different parameters were tested independently (Table I) to determine the optimum head restraint design and position (Figure 1). These were categorised as user configurations (horizontal and vertical gap of the head restraint in relation to the occupant’s head) and design features (head restraint cushion, vertical stalk and seatback canvas stiffness). A Design of Experiments approach using these parameters was implemented to yield a total of 540 different parametric combinations, see Table I. The Neck Injury Criterion (NIC) was used to predict injury outcome [2]. The accuracy of the injury predictions is limited however due to lack of biofidelity of the Hybrid III in assessing neck injuries. The head restraint cushion stiffness was based on static testing of sample commercial cushions.

TABLE I TEST PARAMTERS AND VALUES USED.

Testing Parameters	Values
Horizontal gap (cm)	0, 2.5, 5, 7.5, 10
Vertical gap (cm)	0, 2.5, 5
Cushion Stiffness (kN/m)	13, 25, 60, 78
Stalk Stiffness (Nm/rad)	75, 85, 98
Seatback Canvas Stiffness (kN/m)	82, 164, 246

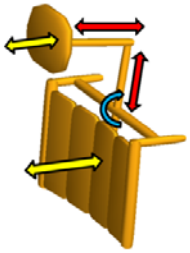

Figure 1. Testing Parameters: (Yellow arrows) Cushion and canvas stiffness. (Blue arrow) Vertical stalk stiffness. (Red arrows) Vertical and horizontal head restraint position.

III. INITIAL FINDINGS

Figure 2 shows a significant improvement in the occupant trajectory and seatback deformation for the revised model compared to the baseline model and the experimental data [1]. The improved deflection of the upright supports for the revised model means it is a more appropriate basis for assessing head restraints attached to the wheelchair handles which connect to the upright supports.

Of the 540 different head restraint simulations carried out, 82 (13%) failed due to model instabilities etc. Figure 3 shows the NIC score as a function of horizontal gap and head restraint cushion stiffness for the remaining 458 cases. The results show horizontal gap between the head and head restraint and the head restraint cushion stiffness to be the most influential parameters on the predicted NIC score, with less influence for vertical gap, stalk stiffness or canvas stiffness.

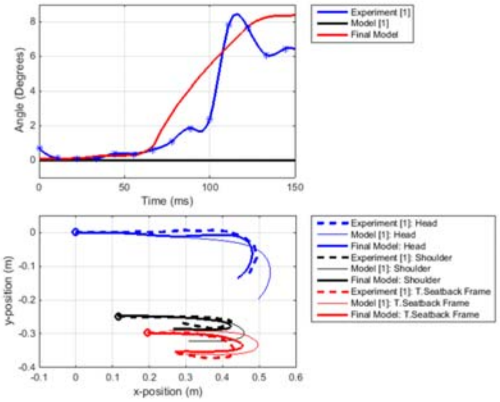

Figure 2: Top: Predicted and measured seatback frame angular deflection; Bottom: Predicted and measured trajectories for the dummy head and shoulders and for the top of the seatback frame.

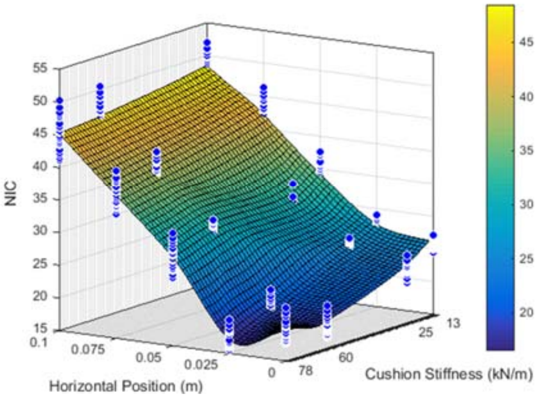

Figure 3: Three dimensional relation between predicted NIC score and horizontal head restraint position and cushion stiffness.

IV. DISCUSSION

The predictive ability of the revised model in relation to seatback deflection and head and shoulder trajectory is improved, see Figure 2. The subsequent parametric analysis with a simplified head restraint design included generally show that minimising the horizontal gap between head and head restraint and increasing cushion stiffness reduce the predicted neck injury risk assessed with the NIC, but the influence of cushion stiffness is significantly less than the influence of the horizontal gap (see Figure 3), similar to what is known for car seat head restraints. A minor anomaly occurs at zero horizontal gap with the stiffest cushion, where the predicted injury risk is slightly higher (3%) than if a larger horizontal gap (2.5cm) or a softer cushion is used. This is because the combination of no gap and a stiff cushion cause neck flexion as opposed to if a softer cushion or a larger gap is present, which allow for the head to translate rearward relative to the chest.

By isolating the positioning configurations (horizontal and vertical gap), the results suggest that the least effective head restraint design (low cushion stiffness) would still reduce the risk of whiplash by 58% compared to no head restraint being present, whilst the most effective head restraint design (high cushion stiffness) would reduce this risk by a further 20%. These results suggest a stiff head restraint cushion should be used when attaching a head restraint system to a manual wheelchair.

V. REFERENCES

[1] Bertocci et al., Medical Engineering & Physics, 2010.

[2] Davidsson et al., IRCOBI Conference, 2013.

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