THE EFFECT OF POSTURAL SUPPORT DEVICES ON REAR IMPACT LOADING FOR WHEELCHAIR OCCUPANTS IN TRANSIT

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ABSTRACT

Wheelchair occupants often remain in their wheelchairs for surface transport. Research has focused on frontal impact, with less emphasis on rear impact. Due to variation in wheelchairs, the use of a standardised wheelchair model may not represent occupant loading in rear impact. Wheelchairs are often adapted to better suit the needs of the occupant and commonly added postural supports were created in a computational model of the BioRID dummy seated in a wheelchair subjected to the IIWPG 16km/h, 10g rear impact pulse. Stiffer supports were found to reduce occupant spinal loading as compliant surfaces bottom-out, causing contact with the stiff underlying structures.

Keywords: WHEELCHAIR DESIGN, DISABLED PERSONS, REAR IMPACTS.

WHEELCHAIR OCCUPANTS often remain in their wheelchair for surface transport, raising significant safety considerations. While research has focused on frontal impact safety, rear impact research has been limited. Wheelchair crash safety design has thus been mostly guided by frontal impact requirements. The current frontal impact safety level requires a wheelchair tiedown and occupant restraint system (WTORS), see figure 1, tested in a 20g frontal impact. The frontal impact response of the wheelchair is tested in (ISO) and the seating system will be separately tested in (ISO final draft). While real world data remains lacking (Wretstrand, Petzäll et al. 2004), staged tests and fundamental crash mechanics suggest that reducing occupant and wheelchair displacement through WTORS and ensuring wheelchair and seating integrity significantly reduces the risk of injury. However, although rear impact accounts for only 5% of fatalities, this crash mode results in 30% of automotive related trauma in the general population, and for more long term injury from low severity impact than any other crash mode (Viano 2002).

Figure 1: Wheelchair Occupant in Transit Using WTORS.

The ISO 10542 surrogate wheelchair is rigid and therefore tests the WTORS in a worst case loading scenario. This wheelchair has also been used to evaluate occupant loading on a BioRID II surrogate wheelchair in the 16km/h 10g IIWPG rear impact pulse (Simms, Madden et al. in press 2008). This showed a high risk of neck injury for occupants of rigid wheelchairs with no head restraint. However, in clinical practice, wheelchair seating systems are frequently customised to provide individual client seating solutions to accommodate postural deformities such as scoliosis, and a rigid wheelchair is not representative of these adaptations. A factory finished wheelchair may not provide adequate support for such an occupant and so additional padding or postural supports devices (PSDs) are added to the wheelchair. This adaptation process invalidates the ISO 7176 frontal impact safety certification of the wheelchair and, in the event of a rear impact, the effect of seating customisations implemented for postural control is generally unknown. This paper uses computational modelling to evaluate postural supports and the influence of their stiffness on occupant loading in rear impact.

METHODS

Sled testing of a surrogate wheelchair and occupant was conducted, figure 2(a) (Simms, Madden et al. in press 2008), to provide the validation data required for a computational model (Walsh, FitzPatrick et al. in submission). Good kinematic and dynamic correlation was achieved: average differences in peak upper body segment accelerations and joint forces/moments were 17%. Evaluation of neck injury criteria also showed good predictive abilities for the model, with a 19% difference for the predicted *NIC* score and a 2% difference for the predicted *Nkm* score (Walsh, FitzPatrick et al. in submission). This provided a validated baseline model of a 50th percentile occupant seated in the surrogate wheelchair, figure 2(b). The occupant model was then altered to introduce scoliosis to the spine using X-ray data, figure 2(c). To create realistic representations of scoliosis, X-rays of real life cases of scoliosis were used and these were provided by the scoliosis clinic from a specialised hospital. Representative cases of mild, moderate and severe scoliosis were identified by a clinician and implemented in Madymo (Walsh, Simms et al. 2008). Rear impact simulations with the scoliotic model revealed that there is an effective increase in the stiffness of the scoliotic spine and this, combined with a point loading effect on the seatback due to scoliosis, results in increased forces on the spine in these cases (Walsh, Simms et al. 2008).

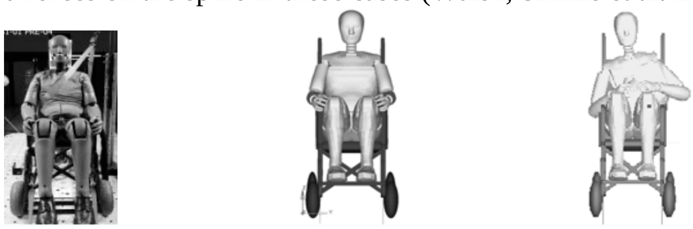


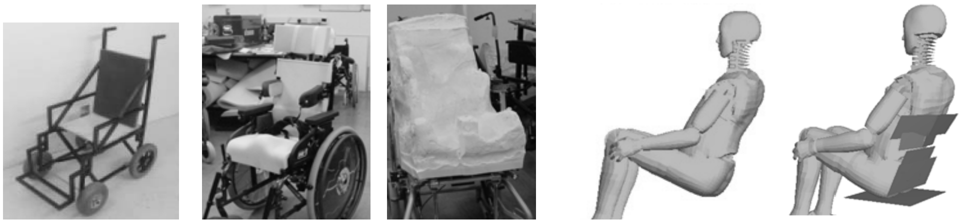
Figure 2:(a) Sled Test (b) Baseline Computational Model (c) Computational Model with Scoliosis

In this paper, the computational model of the wheelchair was adapted to include Postural Support Devices (PSDs). These are common practice in wheelchair seating clinics, and are used to adapt the wheelchair to better fit the altered posture of scoliotic occupants. Their predicted effect in a rear impact and the influence of their stiffness on occupant loading is presented.

To model a clinically customised adapted wheelchair, the baseline computational model of the wheelchair was altered with the guidance of a clinician in the Enable Ireland seating clinic in Dublin. The ISO surrogate wheelchair is shown in figure 3(a) and examples of clinically adapted wheelchairs are shown in figures 3(b) and 3(c), which fit the occupant and provide lateral support. These wheelchairs vary significantly from the factory finished product as the seat and seatback are replaced. The seating system is custom-carved from foam to provide support to the entire surface of the occupant. To model this type of seating system in the computational model, planes were added to fit the contours of the scoliotic torso. Figure 3(d) and (e) shows an example of this for mild scoliosis. Rear impact simulations using the scoliotic BioRID dummy and the 16km/h (10g) IIWPG pulse were then performed for the baseline wheelchair model (corresponding approximately to the ISO surrogate), and for the adapted wheelchair model (corresponding to the representation of the clinically customised seating system). Two different general cases of adapted wheelchair were evaluated: with cushioning and without cushioning.

RESULTS

A different loading pattern on the joints of the spine occurs when a scoliotic occupant is seated in an adapted wheelchair with cushioned PSDs compared to the baseline wheelchair without PSDs. Figure 5 shows the constraint forces in the joint between the ninth and tenth vertebra (T9-T10) for an occupant with a moderate scoliosis. When the scoliotic occupant is seated in an adapted wheelchair with cushioned PSDs, there is a slight reduction in the peak forces on the spine. There is also a delay in reaching these peak values compared to the occupant in the baseline wheelchair. The forces on the spine of the occupant in the adapted wheelchair ramp up at a faster rate than for the baseline wheelchair due to a bottoming-out effect of the cushioned surface of the supports.



(a) **(b)** **(c)** **(d)** **(e)**

Figure 3: (a) ISO 10542 Surrogate Wheelchair (b) Adapted Wheelchair (c) Adapted Wheelchair (d) Curvature of the Torso in Mild Scoliosis (e) Supportive Padding Added to Fit the Contours of the Mild Scoliosis Occupant.

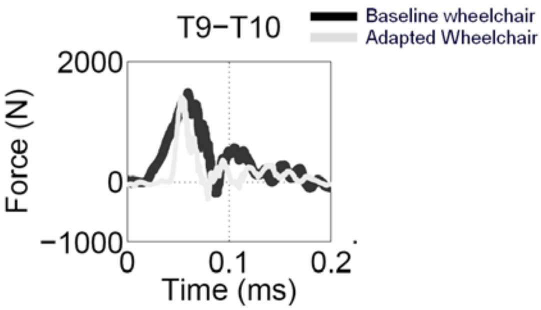


Figure 5: Joint Force for Moderate Scoliosis in Baseline and in Adapted Wheelchair with cushioned PSDs

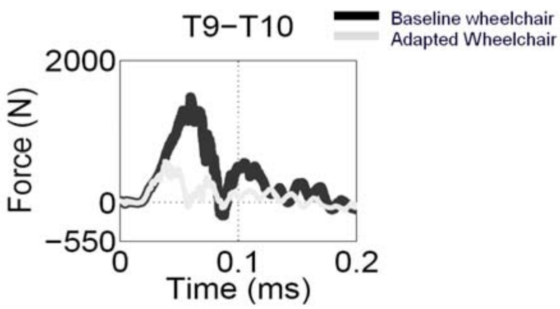


Figure 6: Joint Force for Moderate Scoliosis in Baseline and in Adapted Wheelchair with rigid PSDs

The effect of the cushioning surface on the PSDs was also investigated. When the cushioned layer was removed to model a rigid support the peak forces on the spine were significantly reduced. The constraint force on the joint between the ninth and tenth vertebrae (T9-T10) is shown as a representative case in figure 6.

DISCUSSION

This paper provides a first evaluation of the effect of wheelchair Postural Support Devices (PSDs) on occupant loading in rear impact. This is common practice in seating clinics, but their influence in rear impact is unknown. A limitation of this work is the use of a rigid wheelchair as the baseline model since this leads to increased loading on the spine. However this wheelchair has been used in frontal impact research (Bertocci, Digges et al. 1996) and to investigate wheelchair head restraint performance (Karg and Sprigle 1996; Simms, Madden et al. in press 2008), and the numerical model of the rigid wheelchair provides a comparative tool to investigate the effect of alterations to the baseline occupant and wheelchair in a rear impact.

The addition of PSDs has a significant effect on the interaction of the wheelchair and occupant. The PSDs reduce the initial distance between the occupant and the seatback by fitting to the contours of the occupant's torso. This reduces the occupant's rearward momentum with respect to the wheelchair in a rear impact and hence the contact force on the occupant's torso. The characteristic of the surface of the PSDs is critical: a more pliable surface was found to bottom-out under 10g rear impact and so the occupant contacted against the harder surface beneath. Figure 7 shows the force vs. penetration curve of the contact surface of the wheelchair. In figure 7 the area of the curve which is circled represents the bottoming out of the foam. However, PSDs with a much stiffer surface did not compress under crash loading and so provided more support to the occupant. This reduced the relative rearward movement of the occupant and hence the peak contact forces. Without the supports in place the peak force on the thoracic spine of the scoliotic occupants was 2.3kN, which approaches the value that is known to damage lumbar vertebrae, 2.8kN (Begeman, Visarius et al. 1994). The significantly reduced loading when rigid PSDs were used shows their benefit though their effect on everyday comfort needs to be evaluated.

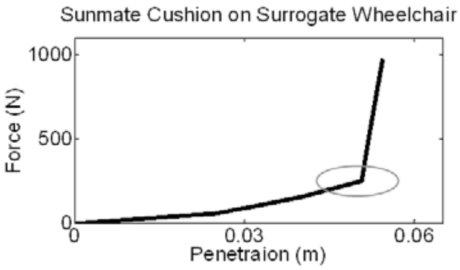


Figure 7: Force vs. Penetration characteristic curve of postural supports.

The effect of adding PSDs in the cervical region is complex and requires further evaluation. However, initial results indicate that compared to the baseline wheelchair, the addition of postural supports increases the NIC but decreases the Nkm score. The axial forces remain low and largely unchanged. The absence of a head restraint results in a high risk of neck injury for all cases simulated.

CONCLUSIONS

The design of the wheelchair seating system has a significant effect on occupant loading in a rear impact. A seat with PSDs designed to fit the contours of the occupant's torso can reduce the impact loading on the occupant. However, the stiffness of the PSDs is critical - too low a stiffness leads to bottoming out and too high a stiffness could lead to other pressure related problems (pressure sores). The influence of PSDs on neck loading in the absence of a head restraint requires further evaluation.

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