An anthropometric study of wheelchair seated drivers of motor vehicles

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Vehicle Safety for Wheelchair Users – The Role of Anthropometry
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INTRODUCTION
Passenger cars are designed to be used by the general adult population. Consequently, vehicle crash protection is developed and assessed using Anthropometric Test Devices (ATDs) and simulation models which purport to represent that population. Present car design based on the anthropometric measurements of non-disabled users may not be appropriate for the wheelchair population. Despite this, Hybrid III ATDs are used to investigate wheelchair and Wheelchair Tie-down and Occupant Restraint System (WTORS) loadings as well as wheelchair user’s kinematics during impact conditions (Dsouza et al. 2010, Rodriguez-Senín et al. 2006). The set-up for WTORS’s dynamic testing and an example of a wheelchair-seated occupant in a real Wheelchair Accessible Vehicle (WAV) are shown in Figure 1. One of the primary considerations of wheelchair transportation safety is facilitating adequate belt fit on the wheelchair-seated occupant’s body to ensure correct restraint during a crash. While this is easy to achieve in tests, the reality is different. Figure 1 clearly demonstrates the need to consider the anthropometric and postural factors of real wheelchair users.

This study was undertaken to investigate the suitability of using current adult Hybrid III ATDs as a representation of adult wheelchair users. As such, the main objective was to collect anthropometric data for the wheelchair population with a focus on the body dimensions most critical for the optimal performance of safety restraint systems. It is expected that this study will provide car converters, manufacturers and researchers with information that can facilitate more effective development of crash protection for wheelchair occupants.

METHODS
Participants (n=20)
A representative sample of convenience consisting of 12 males and 8 female adults using either a manual or a powered wheelchair for their main means of mobility were recruited for this study. The inclusion criteria required all subjects to be aged 18 or over.

Measurement procedure
All subjects were instructed to wear light clothing, which allows for easy palpation of underlying bony landmarks. Additionally, prior to the measurements being taken, the subjects were asked to adopt a normal comfortable seated posture while remaining in their wheelchair as if they were travelling in a car. Anthropometric dimensions were measured using a Harpenden anthropometer. In addition, each subject’s sitting height (head, eye and shoulder) was measured with a standard stadiometer. Except during measurement of the shoulder-elbow and elbow-wrist lengths, the arms were held on the wheelchair armrest.

Variables. Fifteen structural anthropometric dimensions specifically related to the design of car interiors (Halesgrave 1979) were measured for wheelchair adults (see Figure 2).

Figure 1. (a) Set-up for WTORS’s dynamic testing: Rodriguez-Senín et al. and (b) an example of actual wheelchair-seated occupant

Figure 2. Reference diagram for wheelchair users’ anthropometric measurements
Data Analysis. The data collected were analysed by gender. The mean, standard deviation, and the 5th, 50th and 95th percentile values of the distribution for each dimension were calculated by gender. The Student t-test was conducted for all dimensions to determine statistically significant differences (p<0.05) between wheelchair males and wheelchair females.

The mean body dimensions of the 5th and the 50th percentile wheelchair females and the 50th and the 95th percentile wheelchair males were compared to those of the adult Hybrid-III family of ATDs. The differences (%) between the wheelchair user population and the Hybrid III were given respectively by the expressions:

\[
\% \text{ Difference}_{wcu/HIII} = \left( \frac{D_{\text{HIII}} - D_{wcu}}{D_{\text{HIII}}} \right) \times 100 \\
\% \text{ Difference}_{wcu/HIII-50th} = \left( \frac{D_{\text{HIII-50th}} - D_{wcu}}{D_{\text{HIII-50th}}} \right) \times 100
\]

where, \( D_{wcu} \) is the anthropometric dimension for the 5th percentile wheelchair female and the 50th and 95th percentiles wheelchair, \( D_{\text{HIII}} \) is the anthropometric dimension for the corresponding adult Hybrid-III family and \( D_{\text{HIII-50th}} \) is the anthropometric dimension for the Hybrid III 50th percentile male.

RESULTS

The study sample consisted of 12 males and 8 females who used a wheelchair as their primary means of mobility. Student t-tests revealed significant differences between men and women for all height dimensions (p<0.05). As expected, the heights were greater for men than for women.

The sitting height of wheelchair users was lower than the corresponding Hybrid III, reaching an 18.1 % difference for 5th percentile females, and almost 10.0% for 50th and 8 % for 95th percentile males respectively.

Parameters which have a direct impact on the correct fit of the seat belts, such as the chest and the abdominal depths, the seat and the shoulder breadths were also different between wheelchair users and the current adult Hybrid III family. The value for the chest depth of the 50th percentile wheelchair male was greater than that for the Hybrid III 50th percentile male, around 12%, however the difference was considerably more for the extremes of the population, reaching 32.3% greater for the 5th females and 30.6% greater for the 95th males. The seat breadths for wheelchair males were also greater than for Hybrid III, reaching 7.1% difference for the 50th males and 6.6% for the 95th males, while the difference between the 5th wheelchair female and

ATD was more, around 22.5% greater seat breadth for the wheelchair females. A similar trend was found when comparing shoulder breadth values. Wheelchair males showed greater breadth than the corresponding ATDS as did wheelchair females. However, differences were highest between the real females and their ATDs.

The results also show that the lengths of the upper and the lower extremities have different values between wheelchair users and the adult Hybrid III family. The real users showed shorter extremity length. For the elbow-wrist length, there was an 8% difference for the 5th wheelchair females, a 13.1% difference for the 50th percentile male and 4.7% difference for the 95th percentile male.

DISCUSSION

The goal of this study was to determine whether current ATDs represent the anthropometry of wheelchair users for the assessment of wheelchair transportation safety. Results of the Anthropometric survey of wheelchair users conducted here revealed substantial differences between the anthropometrics of the adult wheelchair user population and the anthropometrics of adult Hybrid III ATDs. These findings point to a need for development of testing and simulation which represent the anthropometrics of wheelchair users, if the crash safety of wheelchair-seated vehicle occupants is to be improved.

The sitting height of wheelchair users is significantly lower than that of the adult Hybrid III family, for all percentiles. These results can be partly explained by study participants being allowed to maintain a relaxed posture sitting in their wheelchair. Furthermore, disorders of the central nervous system, which are a common health condition among wheelchair users, often produces changes in the muscle tone of the subjects as muscles are unable to support the spinal column, causing it to bend the torso. This lateral bending alters the person’s posture and mode of sitting to a great extent and hence it may alter the kinematics of the body in a crash. In order to adequately consider vehicle safety design for wheelchair users, both the current Hybrid III ATDs and the occupant computer models must be adapted to reflect postural deformities. Similarly, the influence of muscle stiffening on resulting body kinematics should be investigated.

The current analysis of the wheelchair anthropometric data revealed that the length of the upper extremities of the wheelchair users had been reduced either as a result of their medical conditions or by the presence of concurrent deformity. These findings suggest that wheelchair drivers may sit
closer to the steering wheel and out of position in order to reach the car controls. More research is needed to investigate this situation.

ATD’s body dimensions determine the locations of the restraint system. The routing of seat belts, and hence their effectiveness in restraining the occupant, is affected by the shape of the ATD, particularly in the pelvis and shoulder regions. When selected dimensions of wheelchair users, such as chest and abdominal depths, seat breadth and thigh thickness (which are important parameters with regard to proper fit of standard restraint systems), were compared with the corresponding dimensions of the adult Hybrid III ATDs, there were substantial differences in the dimensional values. Analysis of the anthropometric data revealed that in this study, chest depth, abdominal depth and seat breadth appeared to be higher for wheelchair users. The current ATD shapes represent people who are thinner than wheelchair users, suggesting that they may not be sufficiently representative of the wheelchair population. Further work is planned in order to develop crash simulations of wheelchair occupants using real anthropometry. These models can then be used to realistically assess crash safety and provide pointers to areas of improvement.

CONCLUSION

Comparing the anthropometric features of wheelchair users with the anthropometric characteristics of current adult ATDs indicates that current ATDs do not represent the anthropometric features of wheelchair users. Sitting height, body dimensions of pelvic and shoulder regions such as chest and abdominal depths and shoulder and seat breadths need to be adjusted in order to represent wheelchair users and to assess the effectiveness of the safety belts by routing them in a realistic manner. Ideally, ATDs should reflect postural deformities of the spinal column and muscle stiffness of wheelchair users in order to investigate their influence on resulting body kinematics in a crash. Current ATDs and CAD models do not represent disabled populations. Changes in both the mode of sitting and the existing ATD Injury Assessment Reference Values representing wheelchair-seated occupants need to be made in order to more realistically assess wheelchair-seated vehicle occupant safety.

NOVELTY/TRAFFIC SAFETY IMPLICATIONS

According to the analysis of the anthropometric data collected in this study, the following ATD features are required for better representation of wheelchair users:

- Smaller sitting heights than those of current adult ATDs for each percentile.
- Geometric adaptation to represent the deformed spinal column associated with disorders of the central nervous system of wheelchair users
- Better representation of the shape of wheelchair users, particularly in the pelvis and shoulder regions which are the body regions loaded by seat belts.
- Ability to test crash protection for out of position conditions related to factors such as sitting height, mode of sitting and smaller dimension of the upper extremities due to concurrent deformities.
- Ability to assess injuries caused by contact with the steering wheel and frontal airbag because of the proximity between torso and steering wheel.

Investigation of injury incidents involving wheelchair users during transportation showed that over 71% of wheelchair-seated occupants were incorrectly using a belt restraint system (Schneider et al 2010). Therefore, the features of wheelchair users identified in this study, when incorporated into new ATDs and CAD models, should enable more realistic development of wheelchair occupant safety.

REFERENCES

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