PROXIMITY TO THE STEERING WHEEL FOR OBESE DRIVERS

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ABSTRACT

Obesity increases the risks to motor vehicle occupants of some types of injury in crashes. The effects of obesity on injury causation are not well understood and current prevention efforts do not effectively address the increased vulnerability of individuals with high body mass index (BMI). Proximity to the steering wheel has been associated with increased risk due to airbag deployment, and the steering wheel rim is a source of injury in frontal crashes even with airbags. This study examined the spatial relationship between the steering wheel and drivers with high BMI in a midsize sedan package condition. Driving postures of 52 men and women with BMI from 31 to 59 kg/m^2 (median 38 kg/m^2) were measured in laboratory mockup configured to be representative of a midsize passenger car. Three-dimensional body shape data captured using a laser scanner were aligned to landmarks measured in the driving posture to quantify the relationship between the torso and the steering wheel. Consistent with previous research, higher BMI was associated with decreased clearance relative to the steering wheel. Many drivers with high BMI can be expected to sit with their torsos within 100 mm of the wheel rim. The results suggest that attention should be paid to airbag deployment kinematics and efforts to mitigate the potential for abdominal injury due to steering wheel rim loading for these drivers. A continued focus on improving vehicle and restraint system design for individuals with high BMI is needed.

INTRODUCTION

A driver's proximity to the steering wheel prior to a frontal crash influences load sharing among the restraint system components and may affect injury risk. Several early studies indicated that smaller distances between the occupant and airbag at the time of deployment are associated with higher frequency and severity of airbag-induced injuries, and higher loading in human surrogates [1-4]. The US Insurance Institute for Highway Safety (IIHS) and National Highway Traffic Safety Adminstration recommend that drivers maintain distance of least 250 mm (10 inches) from the steering wheel to reduce risks associated with airbag deployment. Proximity to the steering wheel can also influence airbag deployment kinematics, potentially allowing the steering wheel rim to contact the occupant.

Driver body dimensions, seating position, and belt use are important determinants of whether there is sufficient clearance between the passenger and the steering wheel for the airbag to deploy properly. Manary et al. [5] extracted driver-to-steering wheel proximity distances from a large dataset of driver preferred posture and position in vehicles with a wide range of interior dimensions. Proximity to the steering wheel by three indvidiual dimensions: the driver's chin, manubrium (top of sternum), and the minimum horizontal distance between the driver and ther steering wheel when seated in a normal driving posture. The data were used to develop statistical models of the distribution of clearances between the driver's torso and the steering wheel as function of driver anthropometry, vehicle and seat factors. However, that study was limited by the small number of participants who were obese, less than 10% of the sample.

Obesity increases the risks to occupants of some types of injury in crashes. Obese occupants are at higher risks of fatality and injury in frontal motor vehicle crashes than normal-weight individuals [6-13]. The chest [6,11,14-17] and lower extremities [6,14,18-21] are more likely to be injured for obese than non-obese occupants. These results demonstrate a need to improve understanding of the occupant protection needs of individuals with high body mass index (BMI).

The problem has grown in importance because the fraction and number of adults who are obese has increased significantly worldwide since 1980s according to World Health Organization (WHO). In 2014, 39% of adults aged 18 years and over were overweight and 13% were obese around the world. In the United States, the prevalence of overweight and obesity were 68.8% and 35.7% in 2009-2010, compared with 55.9% and 22.9% in 1988-1994 [22]. A study by Finkelstein et al. [23] predicted that the prevalence of obesity could be up to 42% in the United States in 2030. Currently about 5% of US adults are "morbidly" obese, defined by the CDC (1998) as a BMI $\geq$ 40 kg/m^2. In the United States, the growth rate in the prevalence of a BMI>40 kg/m^2 and a BMI>50 kg/m^2 is twice and three times, respectively, the growth rate of the prevalence of moderate obesity since 2000 [25].

The effects of obesity on injury causation are not well understood and current prevention efforts do not sufficiently address the vulnerability of the high BMI cohort. Injury pattern and severity of injury due to motor vehicle crashes depend on a complex interaction of biomechanical factors, including crash severity and direction and seat belt use. The higher risks of injuries for the obese occupants are believed to be caused primarily by the increased body mass exacerbated by poor belt fit resulting from corpulence (reference). However, the spatial relationship between the steering wheel and torso for drivers with high BMI has not been quantified.

The current study examines the effects of driver characteristics on proximity to the steering wheel in a laboratory study. The horizontal distance from lower rim of the wheel to the torso was measured by combining data from 3D body surface measurements and driving posture.

METHODS

Participants

Fifty-two drivers (26 women and 26 men) were recruited based on BMI classification (Obesity Class I, II, and III) (CDC, 1998). The male study sample averages were 48 (SD= 13) years of age, 1762 (SD =312) mm for stature, 126 (SD =32) kg for weight, and 41 (SD =13) kg/m^2 for body mass index (BMI). The female study sample averages were 46 (SD= 16) years, 1623 (SD = 97) mm for stature, 103 (SD = 19) kg for weight, and 39 (SD = 6) kg/m^2 for BMI. Participants were stratified based on body mass index (BMI) classification, stature, and age.

Vehicle Mockup

Testing was conducted in a driver mockup used in a previous study of posture and belt fit (Reed et al. 2013). The driver mockup included a steering wheel, instrument panel, brake and accelerator pedals, and seat belt. The driver mockup was equipped with a six-way power seat with a power recline adjuster and a large range of vertical adjustment. The seat was mounted on a motorized platform that could be moved fore-aft so that all participants were able to select a comfortable seat position without being censored by the available seat track adjustment range.

The mockup was configured to represent the typical geometry of a midsize sedan. The steering wheel position was 550 mm aft of the accelerator pedal ball of foot reference point (SAE L6) and 646 mm above the heel surface (H17). The steering wheel angle (A18) was set to 25 degrees to vertical. The seat reference point (SgRP) at middle of its adjustment range was set to of 270 mm (SAE H30). Seat back and cushion angles were initially set to 23˚ relative to vertical and 14.5˚ relative to horizontal, respectively (SAE J826). In the vehicle mockup the orientation of the right-handed coordinate system followed SAE J1100 with +X pointing rearward parallel to the long axis of the mockup, +Y pointing to the passenger/inboard side of the mockup, and +Z pointing up. The mockup was also equipped with a three-point seatbelt with a sliding latch plate and a nominal belt webbing width of 45 mm.

Anthropometry

Standard anthropometric measures were taken on each participant to characterize overall body size and shape. A Vitronic VITUS XXL full-body laser scanner and ScanWorX software by Human Solutions was used to record whole-body 3D surface geometry in a seated automotive driving posture. A custom apparatus was used to support the posture that allowed maximum access for the scanner, which captured an average of about 500k surface points for each scan. Fixing the seat back and seat pan angles and setting the limb postures using goniometers and a level carefully controlled participants' posture. A hand-held infrared scanner was used to record contours in body areas shadowed from the whole-body scanner, such as the lap. For the current analysis, scans from a posture designed to match the torso posture for driving was used.

Protocol

The study protocol was approved by the University of Michigan Institutional Review Board (IRB) for Health Behavior and Health Sciences (IRB #HUM00102426). Participants were recruited through online postings and through healthcare providers at the University of Michigan Adult Bariatric Surgery program. Each participant was briefed on the purposes and methods of the study and written consent was obtained. Participants changed into test garments made of thin material that provided good access to body landmarks and anthropometric measures were taken. Body landmark locations were recorded in a laboratory hardseat.

While seated in the driving mockup, the participant was trained in the operation of each seat adjuster and demonstrated use of the components for the investigator. The initial positions of each participant-adjustable component were set to the same midrange values prior to each trial, except that the fore-aft position of the seat was set to different target for men and women to ensure adequate seat travel. The participant entered the mockup and adjusted the seat (fore-aft position, vertical position, cushion angle, backrest angle) to obtain a comfortable driving posture. The participant then donned the belt and assumed a normal driving posture.

The investigator used the FARO arm coordinate digitizer was used to record the participant's posture and points on the vehicle mockup, seat and belt components. A stream of points with approximately 5-mm spacing was recorded along the upper edges of the lap and torso portions of the belt.

Posture and Body Shape Analysis

The body surface landmarks recorded in the vehicle mockup were used to quantify the driving posture relative to the vehicle package.

Surface landmarks were manually extracted from the body scan data, using Meshlab software (meshlab.org). A reference template mesh with 23k vertices was fit to each scan using two-level fitting method [28].

Scan Alignment

To quantify the spatial relationship between the steering wheel and the torso, the 3D surface scan data were aligned to the driving posture and position. The top of the torso was aligned using the suprasternale and cervicale landmarks. To achieve an accurate scan placement in the abdomen area, the surface data were rotated about the Y-axis to match the digitized lap belt location. Figure 1 shows an example of 3D scan data aligned to a driving posture.

Proximity to Steering Wheel

The horizontal distance from the lower rim of the steering wheel to the torso was computed by taking the intersection of a horizontal vector from the most rearward point on the lower rim of the wheel with the torso surface data. Figure 2 shows images of four participants with a range of BMI and minimum horizontal distance to the steering wheel.

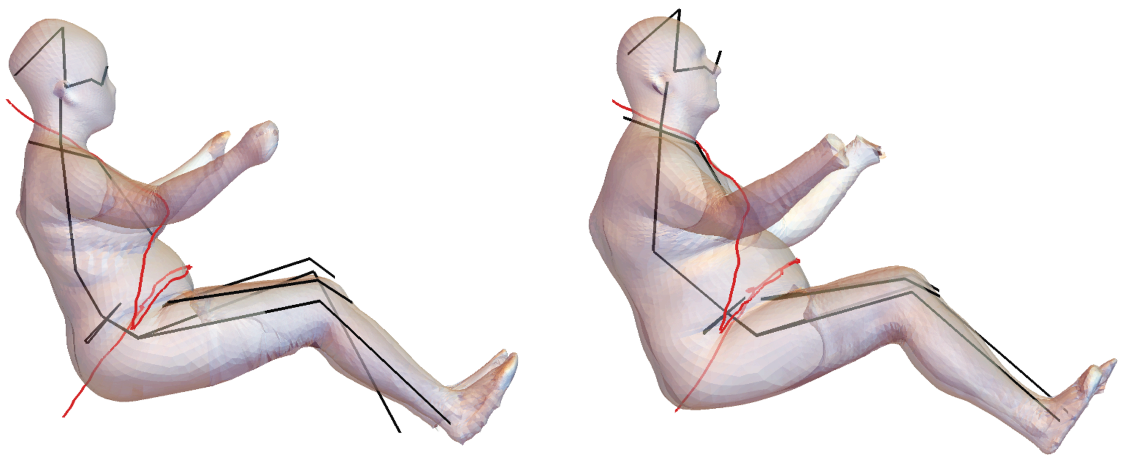

Figure 1. **Representative surface scan data aligned to a participant's driving posture.**

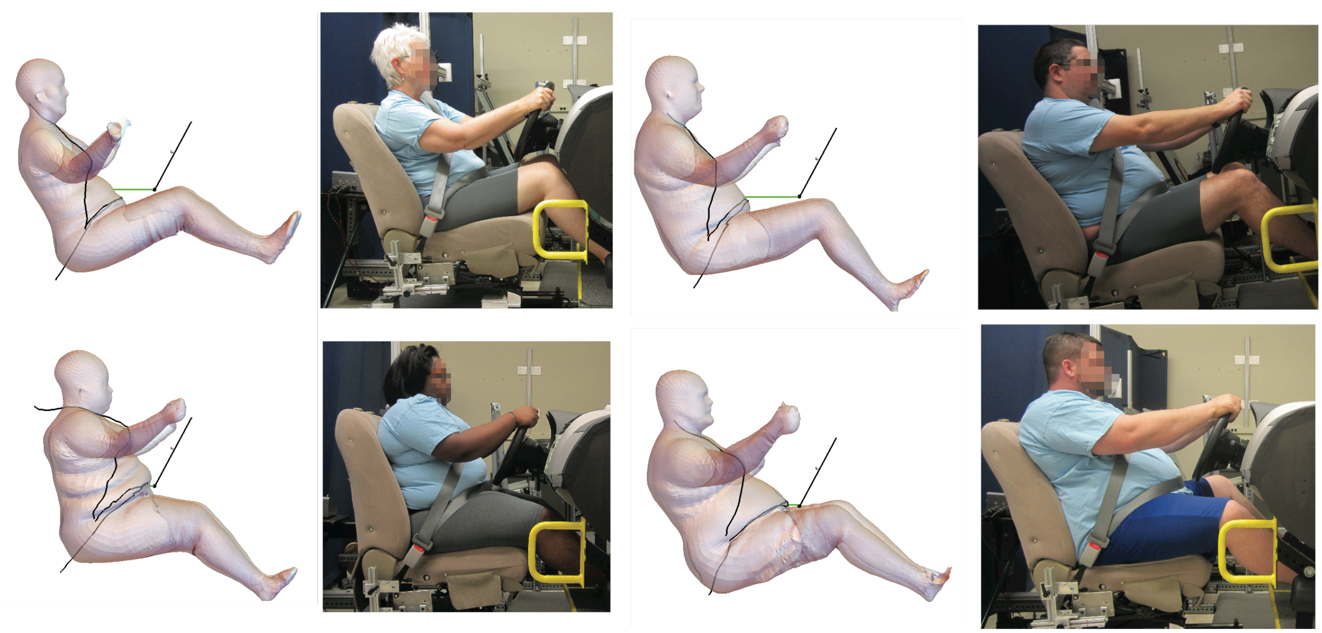

Figure 2. Graphics and photos of aligned data and computed minimum horizontal distance to steering wheel measures for a range of occupant sizes.

RESULTS

Figure 3 illustrates the distribution of the driver horizontal clearance to the steering wheel. The overall mean (SD) of the minimum horizontal clearance was 111 (64) mm. Two participants nearly achieved the recommended 250 mm of clearance, while the minimum clearance was essentially zero, creating a contact condition with the lower rim of the steering wheel.

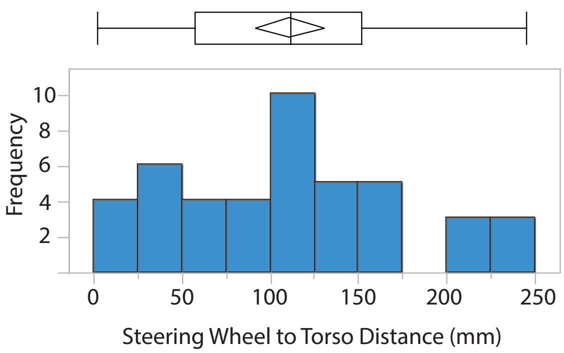

***Figure 3.* Histogram of minimum clearance to the steering wheel.**

Median clearance to steering wheel from torso associated with gender is summarized in Figure 4. Significant differences were observed between women and men, who each had an overall mean (SD) of 92 (60) and 130 (64) mm respectively.

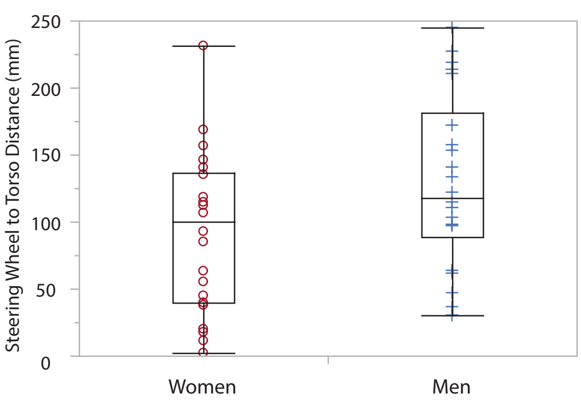

***Figure 4.* Box plot summaries the minimum clearance to steering wheel (mm) by gender.**

A regression analysis was conducted to assess the effects of age, stature, the ratio of erect sitting height to stature (SH/S), and BMI and their two-way interactions as potential predictors. Only the main effects of BMI and stature were significant (p<0.01):

$$\text{Minimum Clearance to Steering Wheel (mm)} = -311.26 - 6.26*\text{BMI} + 0.40*\text{Stature}$$

$$R^2 = 0.59,\ \text{RMSE} = 41.1\ \text{mm}$$

Age had minimal effect, but the significant effect of BMI was similar for men and women (Figure 5). The range of 27 kg/m^2 across the participants resulted in a difference of 204 mm of horizontal distance between the steering wheel and torso, while holding stature at the overall mean value (1705 mm). However, there is considerable scatter in the data that reflects differences in body shape for this high BMI cohort.

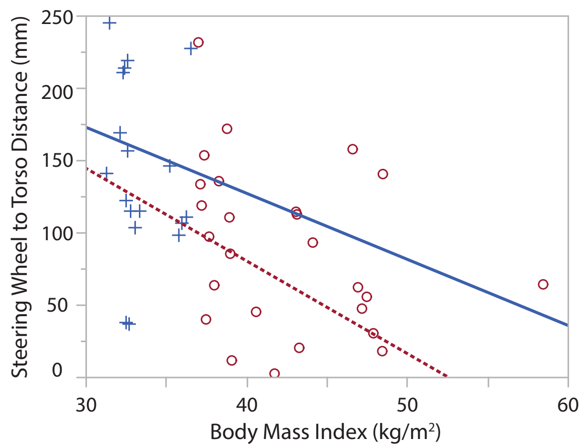

***Figure 5.* Minimum clearance to steering wheel for men (+, —) and women (o, --) as a function of BMI.**

Figure 6 shows the effect of stature for drivers with a BMI < 37 and BMI >37 kg/m^2 which resulted in mean minimum clearance differences of 35 vs. 126 mm, and 60 vs. 218 mm respectively.

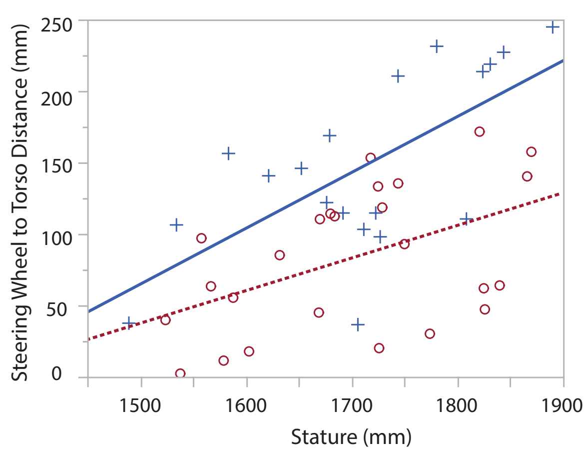

***Figure 6.* Minimum clearance to steering wheel for BMI < 37 kg/m^2 (+, —) and BMI > 37 kg/m^2 (o, --) as a function of stature.**

DISCUSSION

This paper is the first to compute the horizontal distance from steering wheel to torso by combining measurements 3D body surface contours and driving posture. The analysis methodology allows the 3D effects of driver attributes to be visualized relative to the vehicle package configuration.

The results demonstrate the importance of considering proximity to steering wheel for individuals with high BMI. The mean BMI in this sample (40 kg/m^2) is approximately 95th percentile BMI for U.S. adults. None of the participants achieved the recommended 250 mm of clearance, while many participants were found to achieve a minimum clearance that was essentially zero, creating a contact or near-contact condition with the lower rim of the steering wheel. As expected, higher BMI was associated with reduced clearance to the steering wheel. Seat position or stature were also important factors in determining proximity to the steering wheel, and the analysis showed similar patterns for men and women.

These proximity to torso measures represent maximum clearances at the time of air bag deployment. This suggests that attention should be paid to airbag deployment kinematics in conditions with torso interaction and efforts to mitigate the potential for abdominal injury due to steering wheel rim loading for these drivers. A continued focus on improving vehicle and restraint system design for individuals with high BMI is needed.

The analysis is believed to be the first to use 3D body shape data to consider minimum clearance requirements in this area. However, the findings are limited by several issues. The posture measured in the scanner is similar but not identical to the driving posture. Posture differences could change the shape of the lower abdomen. The shape of the torso and lower extremities affect the determination of the horizontal distance. However, the alignment of the scan data using landmarks measured in the mockup minimizes these effects.

Clothing can be expected to affect clearance to the steering wheel. The thin shorts worn for this study minimized clothing bulk, but elastic in the material may have changed the shape of the soft tissue. Clothing effects should be studied further, including the effects of outer garments such as coats worn in cold weather. Further work is also needed to assess the generalizability of these findings to other vehicle layouts and to dynamic, on-road driving situations.

Simulation studies are needed to assess the consequences of proximity to the steering wheel for high-BMI individuals. Studies with human surrogates and finite-element models suggest that smaller distances between the occupant and airbag at the time of deployment are associated with higher frequency and severity of airbag-induced injuries, and higher loading in human surrogates.

CONCLUSIONS

In a cohort of obese individuals measured in a vehicle mockup, none sat with the recommended clearance of 250 mm to the steering wheel, and the mean clearance was less than 115 mm. Further investigation of airbag deployment kinematics and performance for these individuals is warranted.

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