SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

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Seated Posture of Occupants in Wheelchairs

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ABSTRACT – The advent of vehicles with automated driving systems (ADS) will be of particular benefit to people who remain seated in their wheelchairs while traveling. To develop occupant protection systems for integrated wheelchair stations, we need data on how the seated posture of people in wheelchairs differs from a typical automotive posture in a vehicle seat. In this study, we measured the three-dimensional shape of 51 people seated in their personal wheelchairs during several laboratory studies and at field locations. Baseline avatars for each person were generated through HumanShape.org tools. The body segments of these articulated avatars were manually adjusted with custom software to match the collected scan data. The orientations of participant body segments were compared to a nominal posture as a function of occupant characteristics. The findings can be used to help design occupant restraint systems for people seated in wheelchairs.

INTRODUCTION

Safety must be a high a priority as future vehicles with ADS allow new independent transportation options for individuals seated in wheelchairs. Seatbelt fit for people traveling in wheelchairs is often poor, even in vehicles customized for their owners traveling in wheelchairs (Orton et al. 2019). To design ADS-equipped vehicles that provide a similar level of safety for all occupants, we need to understand how the posture of occupants traveling in wheelchairs differs from the typical posture of occupants sitting in vehicle seats. In this study, we obtained and analyzed 3D point cloud data of full-time wheelchair users to quantify and model their posture. We quantified postural variations relative to a nominal automotive posture as a function of multiple subject factors.

METHODS

Data Collection

Three-dimensional point cloud shape data were collected on multiple occasions in both remote and laboratory settings, utilizing 2 or 3 Kinect Azure DK scanners with the collection software outlined in Park et al (2014), or with a 3D systems Sense scanner (Klinich et al. 2021, 2022a, 2022b, 2022c). Data for 49 wheelchair users sitting in their natural seated posture were analyzed. The sample was composed of 21 men, 27 women, and one nonbinary person. Ages and BMI of participants ranged from 18-90 years and 18-55.7, respectively, with medians of 53 years and a BMI of 26.1. Wheelchair make, model, and type also varied, including 34 manual wheelchairs, 14 power wheelchairs, and 1 scooter. Disabilities included spina bifida, amputation, multiple sclerosis, and cerebral palsy.

Avatar Generation

Tools from HumanShape.org were used to generate baseline avatars in an automotive posture using the parameters of age, stature, BMI, sitting height, and waist circumference (Park et al. 2017). Subject stature was self-reported. We approximated waist circumference using the regression model and parameters outlined in Bozeman et al. (2012) and set seated height to 52% of standing height. Although the recommended range for these tools includes statures from 145-190 cm and BMI from 18-40, we were able to generate a reasonable avatar for subjects with higher BMI, but not for the two individuals with characteristics below these ranges who were excluded from analysis. The head, neck, torso, and lower limb postures generated by this tool are intended to be typical of automotive seated postures with a seat height (SAE H30) of 270 mm and a seat back angle (SAE A40) of 23 degrees, which are typical of a driver in a midsize sedan (see Figure 1).

Each baseline avatar was then overlayed with point-cloud data by point-based alignment of the volunteer's trunk using software from Park et al. (2017) that enables subject-specific postural adjustments. The 19 landmarks defined by Reed et al. (2002) were used to define posture. We modified the length and spatial orientation of body segments defined by landmarks to

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match the point cloud data, qualitatively matching the avatar to the volunteer scan as shown in Figure 2.

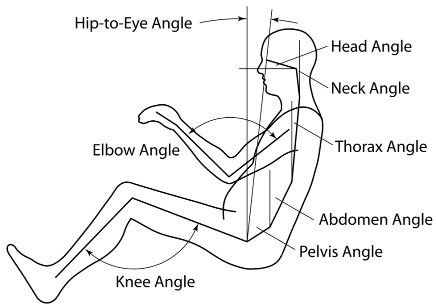

Figure 1: Common seated postural angles on an individual in standard automotive posture (Reed et al. 2002)

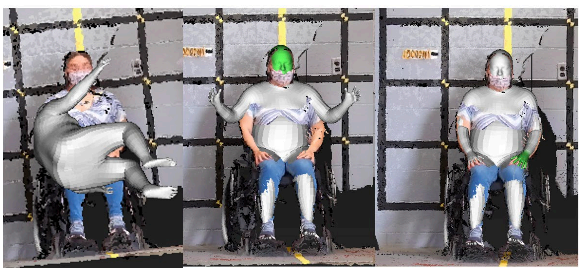

Figure 2: Process of adjusting avatar generated using baseline automotive posture (gray) to align with volunteer posture (color image).

Data Analysis

The landmark data of the adjusted avatars were then used to calculate posture measures shown in Figure 1, as well as a thigh angle with respect to horizontal and a shoulder angle in the YZ plane. Additionally, reference avatars in a typical automotive posture (Park et al. 2017) were generated utilizing 5th- and 50th-percentile female and 50th- and 95th-percentile male stature and body weight (McDowell et al, 2008). We compared mean values of baseline and adjusted postural angles, and also evaluated posture angles as a function of age, BMI, stature, wheelchair type, and type of disability.

RESULTS

Figure 3 compares the XZ (sideview) landmark locations for the 49 adjusted subject avatars to the reference postures, with plot colors showing subjects with different BMI ranges. Table 1 shows the means and standard deviations of posture angles for the baseline and adjusted avatars, as well as p-values calculated using two-sample t-tests with unequal variance. None of the posture angles varied significantly with type of disability. The neck angle was more forward in power wheelchair users versus manual wheelchair users (-12.8 vs. -6.5 deg, p=0.005). Abdomen angles shown in Figure 4 were statistically different with BMI (p<0.001), and the mean shoulder angle of 1.9 deg for subjects with BMI 25-29.9 was less than the value of 4.8 deg for subjects with BMI of 30+ (p<0.001). Male shoulder angle (2.3 deg) was more forward than female shoulder angle (4.5; p=0.02). Pelvis and neck angles also varied between the young and older groups (47.8 vs. 38.2 deg, p=0.044 and -4.0 vs. -12.1 deg, p=0.045, respectively).

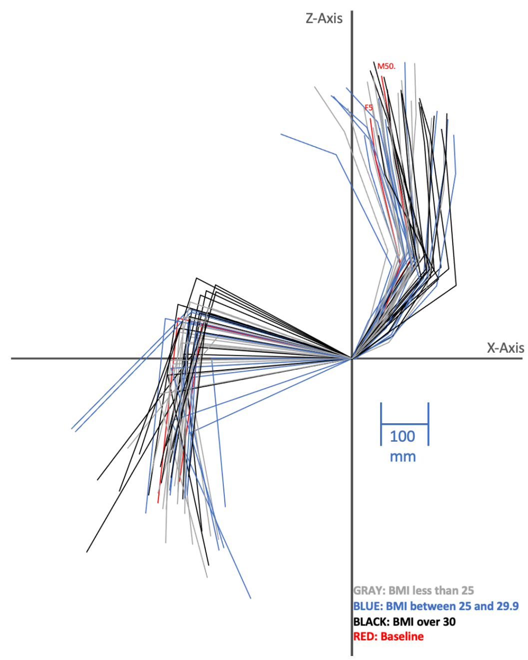

Figure 3: Postural differences between study population in the XZ plane, with origin at pelvis, compared to baseline automotive posture for small female, midsize male, and large male occupants..

Table 1: Differences between select seated posture angles between each person's baseline and adjusted avatars in our study dataset (bold values indicate p-value <0.01).

Angle	Baseline Avatar Mean	Adjusted Avatar Mean	P-Value
Head	-10.6° ± 2.0°	-10.9° ±14.5°	0.899
Neck	-10.8° ± 3.6°	-8.3° ± 9.1°	0.079
Shoulder	1.8° ± 0.5°	3.6° ± 3.3°	**0.001**
Abdomen	30.1° ± 10.5°	32.5° ± 10.5°	0.294
Pelvis	27.8° ± 8.6°	41.6° ± 11.8°	**<.001**
Thigh	14.0° ± 2.4°	7.4° ± 8.6°	**<.001**
Hip-Eye	5.3° ± 2.8°	9.2° ± 9.2°	**0.007**

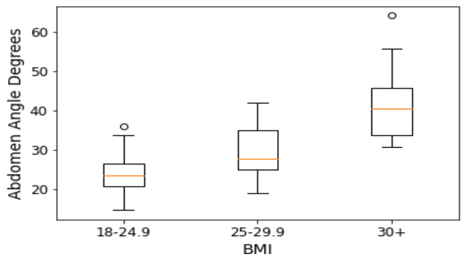

Figure 4: Abdominal angle differences within BMI strata. BMI 18-24.9: n=19, 25-29.9: n=12 30+: n=18

DISCUSSION

The differences in pelvis, hip-eye, and thigh angles in Table 1 and Figure 3 point towards the prevalence of reclined posture among wheelchair users, impacting the efficacy of seatbelts during a crash and increasing the risk of submarining. In particular, the mean thigh angle of an occupant in a wheelchair is closer to horizontal than is typical in automotive postures, and several subjects' thigh angles were at or below horizontal. These posture differences pose a challenge for occupant restraint designers that needs to be addressed, as the space needed to maneuver into a wheelchair station may prevent installation of a knee bolster that could help compensate for poor lap belt fit. Significant posture differences also exist within the volunteer sample by gender, age, and BMI strata.

This study's methodology contains several areas of possible error. Aligning the generated baseline avatar with the obtained 3D point cloud data in individuals with atypical posture is particularly difficult as some body landmarks are not readily located. Additionally, missing point cloud data (when the wheelchair components blocked view of the volunteer) for some subjects introduces additional error into the avatar-adjustment process. The estimation of lumbar spine posture, and hence pelvis and abdomen angles, is particularly difficult. Measures dependent on the lower torso posture are the least reliable.

CONCLUSION

Compared with a typical driver posture, wheelchair users have on average more reclined torsos. This trend was impacted by factors such as BMI, age, gender, and wheelchair type.

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REFERENCES

Bozeman, S. R., Hoaglin, D. C., Burton, T. M., Pashos, C. L., Ben-Joseph, R. H., & Hollenbeak, C. S. (2012). Predicting waist circumference from body mass index. *BMC Medical Research Methodology, 12(1)*, 1-8.

Klinich KD, Manary MA, Boyle KJ, Orton NR, Hu J (2022) Development of an Automated Wheelchair Tiedown and Occupant Restraint System. UMTRI 2021-02.

Klinich KD, Orton NR, Manary MA, McCurry E, Lanigan T (2022) Independent Safety for Wheelchair Users in Automated Vehicles. UMTRI 2022-04.

Klinich KD, Orton NR, Fischer J, Manary MA (2022) Volunteer Evaluation of Wheelchair Accessibility in Vehicles. UMTRI 2022-10.

Klinich KD, Orton NR, Malik L, Zak E, St. Amour M, Manary MA (2021) Volunteer Evaluation of an Automated Wheelchair Tiedown and Occupant Restraint System. UMTRI 2021-04.

Mcdowell, M. A., Fryar, C. D., Ogden, C. L., & Flegal, K. M. (2003). Anthropometric Reference Data for Children and Adults: United States, 2003-2006. *National Health Statistics Report, 10,* 1-48.

Orton, N. R., van Roosmalen, L, & Schneider, L. W. (2019). Summary of Occupant, Wheelchair Tiedown and Occupant Restraint System Configuration Data for Wheelchair-Seated Drivers and Front-Row Passengers in Private Vehicles. UMTRI-2011-30.

Park, B-K.D. and Reed, M.P. (2017). *Characterizing Vehicle Occupant Body Dimensions and Postures Using a Statistical Body Shape Model.* SAE Technical Paper 2017-01-0497. SAE International, Warrendale, PA.

Park, B-K, Lumeng, J.C., Lumeng, C.N., Ebert, S.M., and Reed, M.P. (2014). Child body shape measurements using depth cameras and a statistical body shape model. *Ergonomics.* 58(2):301-309.

Reed, M. R., Manary, M. A., Flannagan, C. A. C., & Schneider, L. W. (2002). A Statistical Method for Predicting Automobile Driving Posture. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 44(4),* 557-568.