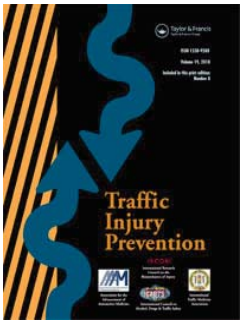

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Driver head locations: Considerations for head restraint design

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ABSTRACT

Objective: U.S. FMVSS 202a requires that a vehicle head restraint lie within a specified distance (55 mm) from the physical headform on the head restraint measurement device (HRMD). Smaller values of this distance, known as backset, are frequently associated with improved protection against neck injury in rear impact. In some vehicles, small backsets are also associated with complaints of head restraint interference with drivers' preferred head positions. The objective of this study is to examine head/head restraint distances using data from a lab study of driving posture to provide guidance for safe and comfortable head restraint design.

Methods: Head positions were measured for 88 U.S. drivers in a laboratory mockup using a seat from a mid-size sedan. The head restraint was removed to allow measurement of drivers' preferred head locations without interference from the head restraint. Rates of disaccommodation, defined as interference between predicted possible head restraint locations and drivers' preferred head locations, were analyzed at HRMD-referenced backsets of 25, 50, 75, and 100 mm measured at 22° and 25° seat back angles.

Results: With HRMD-referenced backsets of 25 mm and 50 mm measured at 25°, the head restraint intersected the preferred head locations of 17.9 and 5.2% of the drivers, respectively. An HRMD-referenced backset measured at 22° produced larger accommodation rates than the same backset measured at 25°.

Conclusions: The reported distribution of occupant head positions and the resulting restrictions on comfortable head restraint position at various HRMD-referenced backsets and seat back angles help provide guidance for head restraint design. Knowing the actual mean driver-selected seat back angle for a particular vehicle seat and the model presented in this work, a manufacturer can choose a head restraint location that will have a high likelihood of complying with FMVSS backset requirements while also achieving minimal disaccommodation. The findings in this study support the flexibility in the current FMVSS 202a that permits testing at more upright seat back angles than the 25° originally proposed.

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Backset; disaccommodation; driver; head location; seat back angle; head restraint

Introduction

Whiplash-associated disorders (WAD) have been frequently attributed to motor vehicle crashes (Gillian et al. 2017). These soft tissue injuries may result from movement of the head and neck relative to the torso during rear impacts (Chapline et al. 2000; Farmer et al. 1999; O'Neill 2000; Stemper et al. 2006). Siegmund et al. (1999) reported that changesin vehicle speed and relative head restraint position are the most significant factors affecting the peak kinematic responses of the head and neck of a driver. The majority of people who experienced WAD reported pain, numbness, and headache (Sekizuka 1998). Based on NASS data, the NHTSA estimated that more than 200,000 whiplash injuries occur per year in the United States (NHTSA 2004). These injuries are typically classified as minor (Abbreviated Injury Scale of 1) given that they are seldom life-threatening (Eriksson 2005).

A head restraint in a front seat is designed to prevent neck injuries in rear impacts. Since 1969 and 1991, U.S. FMVSS 202 has required head restraints in the front seat for all passenger cars for sale in the United States and for light trucks, respectively. In 1982, NHTSA reported that head restraints in passenger cars can reduce injuries to drivers in rear impacts by 13% (Kahane 1982). Walz (2001) reported that head restraints reduced overall injury risk in light trucks involved in rear impacts by 6%.

Epidemiological data have indicated that a gap of greater than 100 mm between the head restraint and the back of the head prior to rear impact is associated with increased symptoms of neck injuries lasting longer than a year (Olsson et al. 1990). Previous simulation studies have shown potential benefits of zero gap between the back of the head and the restraint (i.e., the back of the head is in contact with the

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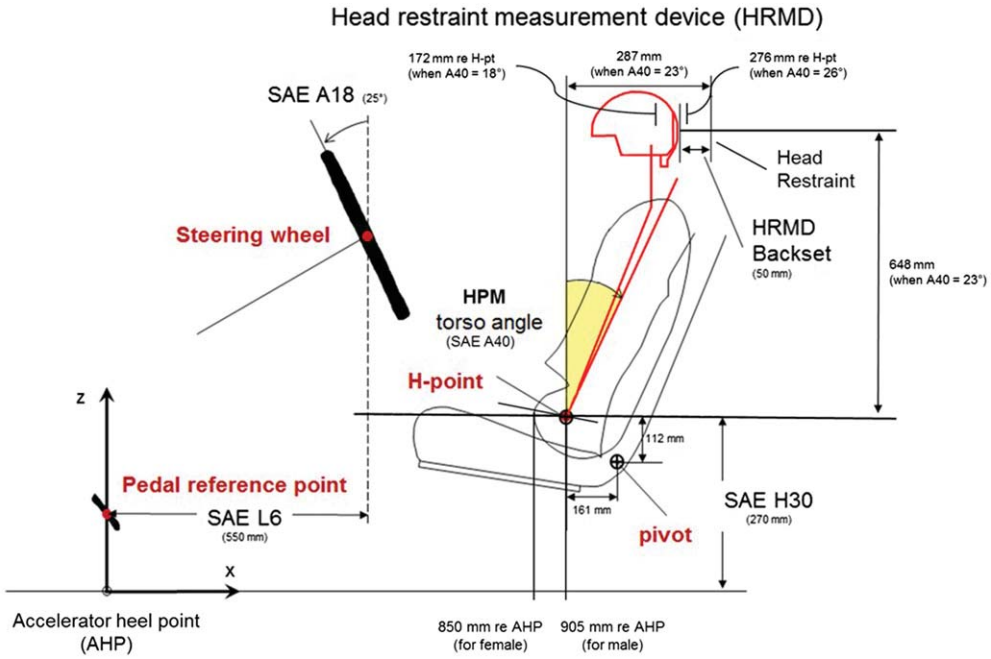

Figure 1. Schematic illustration of HRMD-referenced backset.

head restraint; Eriksson 2005), a maximum initial head restraint gap of 50–60 mm (Sendur et al. 2005; Stemper et al. 2006), and positioning the restraint higher than the center of gravity of the head (Chapline et al. 2000; Farmer et al. 1999, 2003).

FMVSS 202a defines head restraint position using a head restraint measurement device (HRMD) mounted on an SAE J826 H-point machine. The torso angle of the machine is adjusted to the vehicle manufacturer's specified design angle (SAE J826 machine torso angle; see Figure 1) Figure 1 prior to measurement by adjusting the seat back recline angle. The manufacturer's specified design angles of the seat used in this study were 22° and 25°. Note that the models that are presented in this study are continuous, however, so the effects of any reasonable design back angle can be evaluated through interpolation. The standard requires that the distance between the back of the HRMD headform and the head restraint, the "backset" dimension, be no more than 55 mm (NHTSA 2004).

A potential unintended consequence of a small HRMD-referenced backset is interference with occupants' preferred head positions. Using an in-vehicle and laboratory study in which the head restraint did not affect driver posture, Reed et al. (2001) showed that a substantial fraction of drivers could be disaccommodated by head restraint positions that minimally complied with the FMVSS 202 backset requirement. Based upon the distribution of occupant head positions with respect to the head restraint position, Reed et al. (2001) estimated that the required FMVSS 202a backset of 55 mm would interfere with the preferred head positions for 5 to 40% of drivers, depending on the seat back angles used for HRMD measurement. Parkinson and Reed (2006) found that disaccommodation is more likely when the HRMD measurement is performed at a seat back angle that is more reclined than the seat back angle most drivers choose.

The present study aims to examine head/head restraint distances using driver head location data. This article follows the methodology developed by Reed et al. (2001) in presenting an evaluation of preferred head positions that interference with potential head restraint positions. The current article updates Reed's (2001) theoretical results by using data from a recent laboratory study of driving postures with a diverse sample of drivers. The locations of drivers' preferred head positions relative to the seat and seat back are modeled statistically to assess potential head interference at various HRMD-referenced backset distances and seat back angles.

Methods

Participants

Eighty-eight U.S. drivers (42 men and 46 women) were recruited through online advertisements, newspaper advertisements, and word of mouth. The average age, height, and body mass index were 59.0 years (SD =19.7, range =20–89 years), 1,682 mm (SD =113, range =1,435–1,965 mm), and 27.4 kg/m^2 (SD =5.2, range =18.4–48.5 kg/m^2), respectively. Appendix Figure A.1 (histogram; see online supplement) shows detailed demographic information on the participants. Written informed consent was obtained using a protocol approved by the University of Michigan Institutional Review Board for Health Behavior and Health Sciences.

Apparatus and protocol

Testing was conducted in a driver mockup used in a previous study of posture and belt fit (Reed 2013). The mockup was constructed using components from a 2010 sedan that were modified to achieve a high level of adjustability

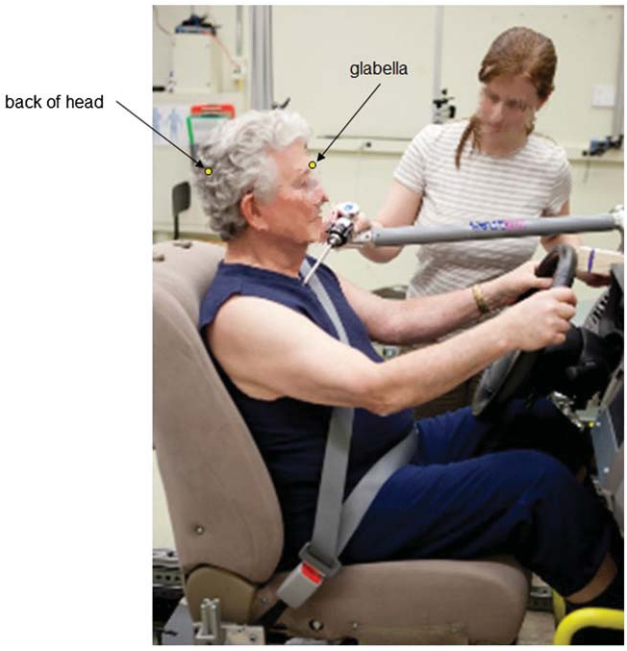

Figure 2. Recording body landmark locations in the vehicle mockup.

(Figure 2). Figure 2 The driver seating package was set to dimensions of a typical midsized sedan. The steering wheel fore–aft position relative to the pedal reference point (SAE L6) was set to 550 mm, the steering wheel height above the heel point (H17) was set to 646 mm, and the steering wheel angle (A18) was fixed at 25° relative to vertical. Seat height (H30) was set to 270 mm at midvertical travel. The initial horizontal seat position along the midvertical H-point travel path was set to 850 mm aft of the accelerator heel point for women and 905 mm for men. Seat back and cushion angles were initially set to 23° relative to vertical and 14.5° relative to horizontal, respectively (SAE J826). The 3-dimensional coordinate system in the present study was defined following SAE J1100 (SAE International 2009): the *x*-axis is positive rearward and the *z*-axis is positive upward.

The seat was equipped with motorized adjustments for fore–aft and vertical positions, seat cushion angle, and seat back angle. 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. During testing, the head restraint was removed to enable participants to adopt a preferred head posture without interference and to facilitate access to posterior head landmarks (Figure 2). A seat from a 2010 Toyota Highlander that provided adjustability for height, cushion angle, and seat back angle was installed on a rail system that provided additional fore–aft adjustability. Powered seat mechanisms provided 239 mm of continuous fore–aft adjustability along a track inclined 5° from horizontal, 50 mm of vertical adjustability, and cushion angle adjustment from 11.5° to 17.5°. Appendix Figure 2 (see online supplement) shows histograms of selected seat back and cushion angles for the men and women. The location of seat back pivot relative to the H-point of the testing seat was 112 mm below and 161 mm aft of the H-point.

A 3-dimensional coordinate measuring machine (FARO Arm, FARO Technology) was used to record participants' postures, including the glabella and back-of-head locations (pressing firmly against the hair). To record the drivers' preferred head locations, all participants were asked to use all of the seat adjustments to obtain a comfortable driving posture. Then, a static driving posture with the hands holding the steering wheel at the 10- and 2-o'clock positions, right foot resting on the accelerator, left foot resting on the floor, and eyes looking forward was recorded. The SAE J826 H-point machine was used to set the seat back and cushion angles as 23° and 14.5°, respectively, and to determine the H-point location. The latter is based on the mean of 3 measurements. The HRMD was not used because no head restraint was present. Seat component locations were also recorded to establish the fore–aft and vertical locations of the seat H-point and to calculate the seat back angle. Both are referenced to measurements made using the SAE J826 H-point machine. The terminology of seat back angle is important to clarify. The *torso angle* of the SAE J826 machine is measured following a standardized installation procedure. This measure, termed SAE A40 (SAE International 2009), is used as the standard measure of seat back angle in the automotive industry, including in the current analysis. The relationship between A40 and the physical orientation of the seat back frame was recorded, along with the H-point, with A40 = 23°, a typical mean driver-selected seat back angle (Manary, Flannagan, et al. 1998). Driver-selected seat back angles were calculated relative to this reference based on the orientation of the seat back frame.

Driver head locations

Prior to analyzing the drivers' backsets, the measured back-of-head locations were adjusted to compensate for measurement errors. Experience with recording driver landmark locations has indicated that face landmarks are more accurately captured than the back-of-head point because the small amount of force required to compress the hair tends to cause the driver's head to move forward slightly. Therefore, the drivers' measured back-of-head *X* locations were adjusted fore–aft such that the *X* distance between the back of head and glabella matched the head length manually measured using a caliper. On average, the back-of-head *X* locations were adjusted by 7 mm rearward.

HRMD calculations

By design, no head restraint was used in the current study to avoid any influence on driver postures. Consequently, all comparisons to HRMD measurements were based on the HRMD geometry and its relationship to the H-point and seat back angle. The most rearward part of the HRMD headform lies 263 mm aft of the H-point with the machine torso back line at 25° with respect to vertical. Consequently, a head restraint meeting the HRMD-referenced backset criterion of 50 mm with seat back angle at 25° would be positioned 313 mm (263 + 50 mm) aft of the H-point. For other

back angles, the fore–aft location of the back of the HRMD head (zero backset) can be calculated as HRMDX =505.5 sin(SBA −3°) + 73, where SBA = SAE A40 (Reed et al. 2001). For example, the value of the HRMD headform lies 237 mm aft of the H-point with the machine torso back line at 22° with respect to vertical. This relationship is dependent only on the geometry of the HRMD and is independent of any seat attributes.

The current calculations assume that the head restraint is rigidly affixed to the seat back and moves with the seat back as it pivots about a single axis. The profile of the head restraint front surface was assumed to be flat, but the results hold reasonably well if the head restraint is contoured because the angle changes are small. The range of seat back angles that drivers selected resulted in a range of fore–aft head restraint locations relative to seat H-point. Using seat geometry data from measurements of 86 vehicles reported in Reed (2013), the mean location of the seat back pivot was 78 (SD =28) mm below and 121 (SD =63) mm aft of H-point. Using the geometry in Figure 1 and seat back angles of 18° and 26° gives a difference in fore–aft head restraint position of 104 mm (276 mm at 26° − 172 mm at 18°). Dividing by the angle range (8°) gives a linear scaling factor (13 mm/°) to convert seat back angle changes into changes in head restraint position.

Driver backset

The horizontal distance from the back of the head to the head restraint was estimated as the difference between the driver's adjusted back-of-head location and the head restraint position that would result for a given combination of HRMD measurements and the driver's chosen seat back angle. We define the seat back geometry as the fore–aft head restraint position with respect to the H-point associated with a seat back angle and an HRMD-measured backset. We then can calculate the backset for a driver at a given seat back angle based on the fore–aft position of the back of the driver's head. For example, if a driver's back-of-head location was 250 mm rearward of the seat H-point at a 22° selected seat back angle, then that driver's backset was calculated as 24 mm (274 mm −250 mm) for the case of an HRMD-referenced backset of 50 mm measured at 25°. Manary, Flannagan, et al. (1998) found no relationship between mean seat back angle and mean driver horizontal head position across vehicles. We used 3 mean driver-selected seat back angles (19.8°, 22.3°, and 24.8°) while using the same subject head location. For example, for a mean driver-selected seat back angle of 19.8°, the difference between mean driver-selected seat back angle in the current data set (21.6°) and that of the tested angle (19.8°) was subtracted from each subject-selected seat back angle. Then we calculated each driver's backset using the aforementioned method.

Disaccommodation estimates

In order to identify the effect of HRMD backset distance and seat back angle on disaccommodation rates for back-of-head locations, disaccommodation rates (defined as the percentage of drivers with zero or negative backset) were calculated using cumulative normal distribution (Gaussian) functions (CDFs) for the mean and SD of the drivers' backsets analyzed at 4 HRMD-referenced backset distances (25, 50, 75, and 100 mm) for 2 seat back angles for HRMD measurement (22° and 25°). Statistical analyses were performed in MATLAB R2011a (Mathworks Inc.).

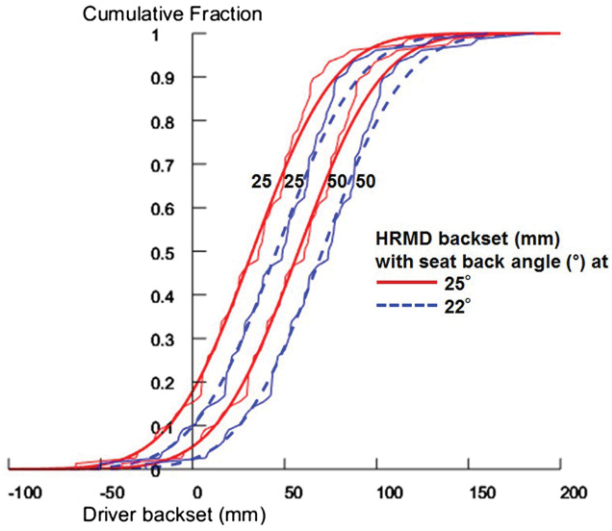

Figure 3. Cumulative driver backset distribution at HRMD-referenced backsets of 50 mm with seat back angles of 25° (solid line) and 22° (dashed line). Mid-size sedan package condition: H30 = 270 mm, L6 = 550 mm; mean driver-selected seat back angle =21.6°. The thin line indicates empirical CDFs.

Results

Driver-selected seat back angle was found to be significantly associated with back-of-head X and Z locations relative to the seat H-point (see Appendix Figure 3, online supplement). An increase in driver-selected seat back angle (A40) of 1° was associated with a 9.0-mm more rearward back-of-head X location ($P < .001$, $R^2 = 0.38$). Back-of-head Z location was not practically influenced by A40 ($P = .002$, $R^2 = 0.02$). The mean ± SD of driver-selected seat back angles for the present study is 21.6° ± 2.9°, which is comparable to the 22.3° ± 2.5° reported by Reed et al. (2001).

Due to the geometry of the HRMD, the HRMD-referenced backset distance and seat back angle used for HRMD measurement had substantial effects on the driver backset. Figure 3 shows the distribution of driver backset for a set of HRMD-referenced backsets (25 and 50 mm) with seat back angles of 25° and 22°. With an HRMD-referenced backset of 50 mm measured at 25° (Figure 3), the mean ± SD of driver backsets was calculated as 57.6 ± 35.4 mm and the head restraint intersected the preferred head positions of about 5.2% of the drivers (intersection indicated by negative driver backset). For HRMD-referenced backsets of 25, 75, and 100 mm, the mean ± SD of driver backsets was 32.6 ± 35.4 mm, 82.6 ± 35.4 mm, and 107.6 ± 35.4 mm, corresponding to disaccommodation rates of 17.9, 1.0, and 0.1%, respectively.

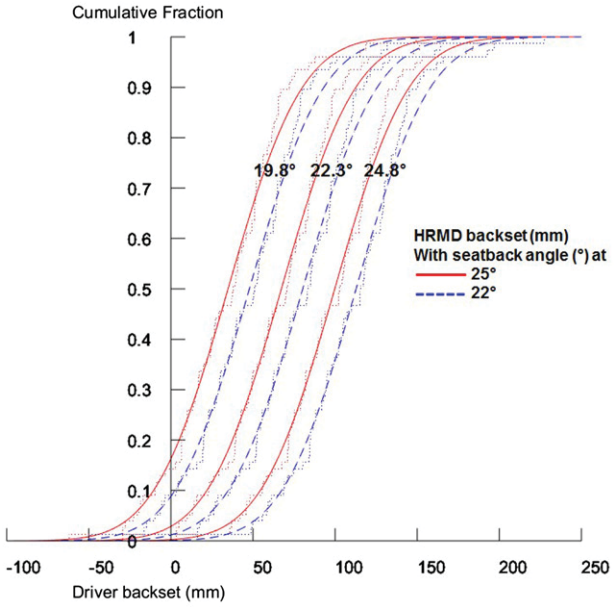

Figure 4. Cumulative driver backset distributions measured by 50-mm HRMD-referenced backset at 25° (solid line) vs. 22° (dashed line) for 3 mean driver-selected seat back angles (19.8°, 22.3°, and 24.8°). The small dotted line indicates empirical CDFs.

In general, a 50-mm HRMD-referenced backset measured at 22° will produce larger driver backsets than the same HRMD-referenced backset measured at 25°, because drivers usually select more upright seat back angles than 25°. Using the geometry of the HRMD reported by Reed et al. (2001), a 50-mm backset measurement at 25° is equivalent to 89.0 mm (50.0 mm $+3° \times 13.0$ mm) backset at 22°. Therefore, for a fixed HRMD-referenced backset specification, measured at a more upright seat back angle, results in greater backset for drivers (greater accommodation). Conversely, measuring at a reclined seat back angle results in shortened backset for driver (less accommodation). For example, if seat manufacturer designs a 50-mm HRMD-referenced backset with a seat back angle of 25° but drivers tend to select a more upright seat back angle (e.g., 22°), they will tend to have a head restraint closer than intended. When the HRMD target backset is established at a more upright angle, such as 22°, driver disaccommodation is reduced (Figure 3). In the present study, the mean driver backset for a 50-mm HRMD-referenced backset measured at 22° was 70.6 mm, compared with 57.6 mm for a 50-mm HRMD-referenced backset measured at 25°. The mean driver backset of each HRMD-referenced backset of 25, 50, 75, and 100 mm at 22° was 13.0 mm larger for the same HRMD-referenced backsets at 25°. The corresponding disaccommodation rates were computed as 9.9, 2.3, 0.3, and 0.03%, respectively with HRMD-referenced backsets of 25, 50, 75, and 100 mm at a 22° seat back angle.

Mean driver-selected seat back angle also has a substantial effect on the distribution of driver backsets. To enable comparison with the distribution of mean driver-selected seat back angles, the range of mean driver-selected seat back angles across vehicles of $22.3° \pm 2.5°$ (19.8° to 24.8°) was simulated. Figure 4 (solid line) shows the distribution of driver backsets that would be obtained if the mean selected seat back angle was 19.8°, 22.3°, or 24.8° for an HRMD-referenced backset of 50 mm measured at a 25° seat back angle. The mean driver backset ranged from 34.8 mm for a mean driver-selected seat back angle of 19.8° to 99.8 mm for a mean seat back angle of 24.8°. The distribution of the 50-mm HRMD-referenced backset at 25° with a range of mean driver-selected seat back angles of 19.8°, 22.3°, or 24.8° resulted in disaccommodation of 16.3, 2.9, and 0.2% of drivers' preferred head locations, respectively.

Figure 4 (dotted line) shows the CDF of driver backsets at a 50-mm HRMD-referenced backset of 22° with a range of mean driver-selected seat back angles (19.8°, 22.3°, and 24.8°). The corresponding mean driver backsets were calculated as 47.8, 80.3, and 112.8 mm, respectively. The disaccommodation rates were 8.8, 1.2, and 0.1%, respectively. Table A1 (see online supplement) presents results for a range of conditions.

Discussion

The present study examined the effects of (1) HRMD-referenced backset distances, (2) seat back angle (i.e., machine torso angle) at which the HRMD measurement is performed, (3) mean driver-selected seat back angle, and (4) their interrelationships on the disaccommodation rates of drivers' preferred head locations. All of these factors have effects. The HRMD-referenced backset distance requirement was also found to have a substantial effect on the disaccommodation rate of drivers' preferred head locations. In the present study, the disaccommodation rate of a 25-mm vs. 50-mm HRMD-referenced backset at a 25° seat back angle was more than 3 times higher. The findings in this study support the flexibility in the current FMVSS 202a that permits testing at more upright seat back angles than the 25° originally proposed. Note that Insurance Institute for Highway Safety still tests at 25°, and manufacturers might consider using a 25° back angle for other reasons, including international homologation. Hence, the current model, which enables evaluation of the consequences of alternative measurement angles, remains relevant.

Since the FMVSS 55-mm HRMD backset distance lies within the current testing range (25–100 mm), the disaccommodation rate for a 55-mm backset can be estimated based on the results from this study. In addition, the mean and standard deviation of driver-selected seat back angles measured in this study were 21.6° and 2.9°, respectively, in the range of 22°–25° that would be applicable to 2017 models. More generally, the models presented in this article allow consideration of the effects of manufacturing margins that must be incorporated into designs. For example, an original equipment manufacturer cannot design for an average performance that minimally complies with FMVSS 202a; due to build variability, it is necessary to design for a shorter backset. The current model allows the consequences for disaccommodation of the combination of a design target and an expectation for build variability to be quantitatively considered. In general, a 50-mm HRMD backset measured at 22° will provide larger driver backsets than the same backset measured at 25°. This is the core of the challenge for head

restraint design: Predicting mean driver-selected seat back angle and choosing the measurement position (and target backset). Accurate knowledge of driver-selected seat back angle is critical; the models presented in this article provide manufacturers with the ability to consider the effects of discrepancies between expected and actual driver-selected seat back angle distributions.

Disaccommodation rates in the present study were about half those reported by Reed et al. (2001). One of possible explanations is that two thirds of the participants in the present study were over 60 years old. The participants in this study were selected to to represent key anthropometric characteristics (height and body mass index) of the U.S. adult population. The age distribution was deliberately skewed toward older individuals, due to other objectives of the study. Because the results do not show strong covariate effects, the discrepancies between the driver population in any particular vehicle and the driver sample used for our models are not expected to be large. The current data included a large cohort of older drivers who are over age 60. In this data set, head locations of older drivers have been found to be slightly more forward than those of younger drivers (Park et al. 2016), which would increase mean driver backset and subsequently decrease disaccommodation rates. This may account in part for the difference in driver backsets between the current study and Reed et al. (2001). Note that the disaccommodation rate of the HRMD 50-mm–25° backset in Reed et al. (2001) was 13% at a mean 22.3° driver-selected seat back angle, but the rate in the current study was 5.2% at a mean 21.6° driver-selected seat back angle. The generalizability of these results is constrained by the limitations of its underlying data set as well as the modeling assumptions. Note that the pivot location in the testing seat (112 mm below and 161 mm aft of the H-point) is within the range of seat pivot locations used over the past 2 decades, based on measurements made at the University of Michigan Transportation Research Institute in many studies. Among the limitations was the use of a mockup equipped with a single seat and test conditions limited to a mid-size sedan package. The results were also limited by the static and laboratory context, which means that drivers' head locations measured in naturalistic driving may not be identical to the static positions in the laboratory (Lenard et al. 2015); however, driving postures measured in the laboratory have shown good correlation with in-vehicle measurements from previous studies (Manary, Flannagan, et al. 1998; Reed et al. 1999). The back-of-head measurements did not take into account hair, vehicle motions, or head motions. All of these factors would tend to increase subjective disaccommodation and potential complaints of head/head restraint interference. The relationship between seat back angle and fore–aft head restraint location was modeled based on an average seat back pivot location and assuming that the head restraint and seat back rotate as a unit. Although different pivot locations and more complex head restraint kinematics are possible and would be expected to affect the distributions of backset across the driver population, we believe that the range of pivots can have minimal effects given the relatively large distance from the pivot to the head restraint.

This procedure was intended to minimize the bias that would have resulted if the seat were set to an extreme initial position, while also allowing participants to enter the mockup comfortably. We have found in previous studies that using an extreme initial position (for example, seat full rear) results in a bias that can only be accounted for by averaging trials from other extreme positions. This is not practically achievable, due to the large number of conditions required. Instead, we use our previous knowledge of driver posture to set initial conditions close to the expected mean, which minimizes bias. We required the participants to demonstrate the seat adjustments, reducing the chance that they would simply accept the initial conditions as optimal.

We chose to use the simulation method for two reasons. First, the regression-based approach helps to limit the potential effects of the nonrepresentativeness of the sample. Second, the method enables a direct comparison with previous results.

The current study was not designed specifically to address head restraint disaccommodation. However, the disaccommodation rate in any particular seat is much less interesting than the relationships between head position and seat back angle. The most important limitation of the study is that a single seat was used. Previous studies have demonstrated that mean driver-selected seat back angles differ across vehicles over a range of approximately 5°, whereas driver torso recline angles vary minimally. This means that the relationship between the SAE machine measurement of seat back angle and the seat back angle that the driver experiences is not consistent across seats. This is the primary reason why it is critical to know the actual mean driver-selected seat back angle for a particular vehicle seat when choosing the head restraint location. With that information, and the model presented in this work, a manufacturer can choose a head restraint location that will have a high likelihood of complying with backset requirements while also achieving minimal disaccommodation.

The consequences of the type of disaccommodation analyzed in this study should be examined in further studies. One important consideration is the behavioral adaptations of drivers to disaccommodation. Some individuals may be able to adjust the seat back angle and other components to clear the obstruction while maintaining a comfortable driving posture, but the extent to which such adjustments reduce the overall disaccommodation problem is currently unknown.

The results quantify the importance of driver-selected seat back angle on backset and accommodation. Previous work has demonstrated that the mean driver-selected seat back angle varies across vehicles between about 19° and 27°, though driver torso postures vary little (Manary, Flannagan, et al. 1998; Reed et al. 2002). No relationship between manufacturer-specified "design" seat back angle and driver posture exists (Manary, Reed, et al. 1998), nor do drivers sit with systematically different torso recline angles in vehicles from different categories (SUVs and sedans, for example). These findings demonstrate that the interaction between the

SAE J826 H-point machine and the seat back is not fully representative of human interactions, because the same mean driver torso postures are associated with a range of mean seat back angles. Consequently, manufacturers should carefully measure driver seat back angles as part of the process of design validation to ensure that they match expectations. A seat in which drivers select more upright back angles than anticipated is likely to result in a higher percentages of drivers disaccommodated by the head restraint. If the backset is specified at a more upright back angle, the mean backset for drivers will increase. Many of the early problems with disaccommodation resulted from the Insurance Institute for Highway Safety's procedure of measuring at 25°, which is larger than the mean selected seat back angle in many vehicles. If the mean selected seat back angle were, say, 22° (not uncommon), the proportion of drivers who are disaccommodated would be quite large.

One option for reducing average driver backset while also reducing disaccommodation is to link the head restraint position with respect to the seat back to seat back angle. Parkinson and Reed (2006) presented a method for computing the optimal kinematic relationship. One important consequence of such a system is that it would provide more similar levels of accommodation and backset for men and women than systems that move 1:1 with the seat back would provide.

The focus in this analysis on accommodation of preferred head position is only one of many considerations in the design of head restraints. Computational human models that evaluate the design of the head restraint and body size, shape, and posture of the occupant are also needed to assess the influence of head restraints on neck injury risk in crashes.

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