SAE TECHNICAL PAPER SERIES

2001-01-2821

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Reprinted From: Truck Safety and Driver Issues (SP–1652)

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL

International Truck and Bus Meeting and Exhibition
Chicago, Illinois
November 12-14, 2001

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

ISSN 0148-7191

Printed in USA

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ABSTRACT

Effective application of human figure models to truck interior design requires accurate data on the postures and positions of truck drivers. Errors in positioning of figure models propagate to errors in reach, visibility, and other analyses. This paper describes methods used in a recent study to measure in-vehicle driving postures in Class 6, 7, and 8 trucks. A three-dimensional coordinate measurement machine was used to measure body landmark locations after a driver completed a short road course. The data were used to validate posture-prediction models developed in a previous laboratory study. Vehicle calibration, driver selection, and testing methods are reviewed.

INTRODUCTION

Human figure models are now widely used in vehicle interior design, including the design of truck cabs. Proper positioning and posturing of the computer manikin is essential for meaningful ergonomic analyses. The locations of important body landmarks (such as the eyes) should match the average location expected for people who match the body dimensions of the manikin under the specified task conditions. Changes in manikin size or in vehicle geometry (steering wheel position, for example) should produce corresponding changes in body posture and position.

During the past decade, statistical procedures have been developed to use data from laboratory studies of the factors affecting driving posture to create accurate posture prediction models (1). These methods have been applied to data from passenger cars, and, more recently, in a large-scale laboratory study of truck- and bus-driving postures (2). This paper presents methods used in an in-vehicle study conducted to assess the validity of the models created from laboratory data. Twenty-four men and women with truck driving experience operated each of six trucks over a test track route. Following the drive, posture was recorded by digitizing body landmark locations.

METHODS

Vehicles

Six truck models were selected that spanned a range of interior geometry. Table 1 lists the trucks and the available adjustment features. The International 4700 and DAF 45 were straight trucks; the others were tested without trailers. The Class-8 trucks had highly adjustable seats, including wide ranges of vertical, fore-aft, and back rest recliner travel. The DAF 45, although equipped with a height-adjustable seat, was tested with the seat height fixed. By design, the test vehicle pool was mostly Class-8 trucks, but the inclusion of the two smaller trucks allows the results to be generalized more widely.

Vehicle Measurement

An important component of an in-vehicle posture study is accurate characterization of the interior geometry and ranges of adjustment. H-point measurements were conducted in each vehicle using the SAE H-point machine. Figure 1 shows the H-point machine being used in a truck. A FARO Arm coordinate measurement machine was used to record the locations of the H-point and reference points on the vehicle and seat. H-point drops were conducted at the middle seat height and a seat back angle (manikin torso angle) of 15 degrees. The location of the H-point relative to reference points on each of the moveable seat components (pan and back rest) was recorded. After removing the manikin, the locations of the reference points were tracked as the seat components were moved through their adjustment range. This procedure was used to define the H-point travel range and Accelerator Heel Point (AHP) locations for each truck.

FARO Arm Procedures

Measurement of vehicle interiors, and of drivers within the vehicle, is complicated by access and alignment issues. The FARO Arm (Gold Series, with an eight-foot reach) was mounted on a height adjustable platform that could be wheeled up to the side of the vehicle cab. The experimenter stood on the vehicle running board when measuring locations within the vehicle. Three tape reference marks were placed on the outside of the vehicle just beyond the perimeter of the driver's door. The locations of these marks were recorded before and after the experimenter mounted the running board. These data allow the subsequent posture-measurement data to be aligned to compensate for the small changes in truck cab orientation produced by the experimenter standing on the running board.

Each time a measurement was made in the cab (including H-point and driver posture measurements) an origin was established at a particular hard point that differed for each vehicle (typically a bolt head on the running board). A vehicle longitudinal axis was established using points on an adjacent line, thereby setting (with vertical) a consistent coordinate system. The vehicle reference points allow all of the data to be expressed in a vehicle package coordinate system referenced to the Accelerator Heel Point (or to any other cab reference point of interest).

Table 1
Test Vehicles

Truck Model	**Seat Adjustments**	**Steering Column Adjustments**
Peterbilt 379 (Class 8)	Height Fore-aft Seat pan length Seat pan angle Back rest angle	Tilt and telescope
International Eagle (Class 8)	Height Fore-aft Seat pan length Seat pan angle Back rest angle	Tilt and Telescope
Freightliner Century (Class 8)	Height Fore-aft Seat pan length Seat pan angle Back rest angle	Tilt and Telescope
Volvo VN (Class 8)	Height Fore-aft Seat pan length Seat pan angle Back rest angle	Tilt and telescope
International 4700 (Class 6)	Height Fore-aft Back rest angle	Fixed
DAF 45 (Class 5)	Fixed height Fore-aft Back rest angle	Fixed

Figure 1. H-point measurement in a truck cab using the FARO Arm.

Participants

Testing was conducted with 17 men and 7 women (24 total), all holders of commercial driver licenses. The drivers had varied levels of experience, and included students training to be truck drivers (n=7), current or former professional drivers (n=14), and engineers who had undergone basic driver training (n=3). Participants who were not PACCAR employees were compensated for their participation. Drivers were selected to represent diversity in gender and key anthropometric dimensions, including stature and weight. The standard anthropometric dimensions listed in Table 2 were measured.

Recruiting suitable participants is the most difficult part of conducting ergonomic studies of truck drivers. People with substantial driving experience are desired, both because the test vehicles must be operated safely and because truck driving experience may lead drivers to choose different postures and positions than they would otherwise assume. In this study, access to the professional drivers at PACCAR provided a core of experienced participants with a wide range of body dimensions. The truck-driving students had much less experience (months, typically), but had sufficient on-road time to anticipate and respond to the demands of driving.

Table 2
Standard Anthropometric Dimensions
Recorded for Each Participant

Weight (without shoes)	Hand Length
Stature (without shoes)	Head Breadth
Stature (with shoes)	Head Length
Shoe Length	Sitting Height
Shoe Width	Seated Hip Breadth
Shoe Type	Eye Height, Sitting
Acro-Olecranon Length	Knee Height, Sitting
Elbow-Fingertip Length	Buttock to Knee Length
Bideltoid Breadth	Abd. Width (relaxed sitting)
Fingertip Reach	Hip Breadth, Sitting
Thumb Tip Reach	Seated Waist Circ. (max)
Standing Waist Circumference (max)	Abd. Depth (relaxed sitting)
Interpupillary Breadth	

Procedures

After being briefed on the test procedures, participants signed a consent form and the standard anthropometric dimensions in Table 2 were taken. The participants drove the six trucks in random order around a test track at the PACCAR Technical Center using both a high-speed oval and a durability road course. The goal of the short-duration drive was to familiarize the driver with the vehicle and ensure that the seat position, steering wheel placement, and body posture were representative of the driving position the subject would likely adopt for a longer duration drive. The investigator explained all of the available adjustments (steering wheel tilt, seat height, seat cushion angle, seat back angle and seat track travel) to the subject. The driver was given 5 to 10 minutes to become familiar with all of the controls and was asked to set all of the components to preferred positions. After a comfortable and alert posture was reached, the participant drove the vehicle out onto the test track. The total amount of time driving a single vehicle was usually less than 15 minutes, with two laps of the high-speed track and two laps of the durability track being typical. If the driver needed more time to make seat and wheel adjustments, additional laps of the track were taken.

The high-speed track consists of a 1.6 mile oval with two 15-ft lanes, and 800-ft-radius curves. The curves are banked at 12- and 29-% for equivalent “hands off the wheel” straight line driving at 35 and 60 mph respectively. On this portion of the track drivers remained on the inside lane at 35 mph. The durability track consists of a 1.5-mile loop inside the high-speed oval. The lane used for this test contained no durability events (i.e. chuck-holes, chevrons, broken concrete, etc.). The lane is about 12 feet wide and there are a series of gentle right and left corners on the course, as well as full 90-degree corners to get onto, and off of the track. The durability track was traveled at a speed of 25 to 30 mph. Using both tracks allowed the drivers several opportunities to brake and shift, as well as manipulate the steering wheel in a manner representative of normal street driving.

At the end of the familiarization drive, the participant drove the vehicle into a shop facility bay, where the FARO Arm was used to digitize various body, seat, and vehicle landmarks to define the driving posture and position. The landmarks shown in Figure 2 were measured on all subjects while they remained seated in the cab following their drive, using methods developed in previous studies (3). The investigator located all of the landmarks with the exception of the right and left anterior superior iliac spine (ASIS) and substernale landmarks. The investigator instructed the participant how to locate these bony landmarks prior to sitting in the seat. During testing, the participant located these landmarks and helped the investigator to digitize their locations.

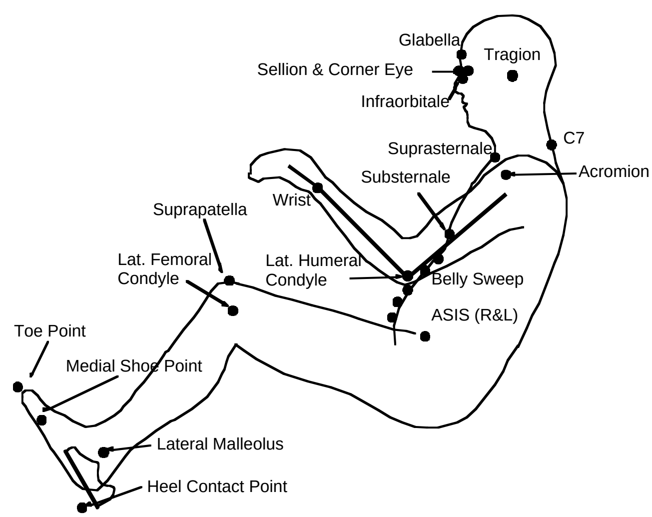

Figure 2. Schematic of body landmarks.

The participants were told to sit as they did while driving the vehicles, with their foot on the throttle (initial position), their hands on the wheel, and eyes looking forward to where the center of the roadway would be. The points associated with the legs in Figure 2 were captured for several pedalapplication postures. The primary posture was recorded as if the driver were driving down the road (right foot on the throttle, left resting comfortably on the floor). In addition, left leg postures were captured for separate initial and fully depressed clutch positions. An approximation of the belly contour was captured by taking 5 points at the driver centerline between the substernale and belt line of the driver. Each driver's file was aligned using repeatable cab reference points from the calibration file created prior to data collection.

It was important to remind subjects to maintain the desired "driving" posture, especially when the points were taken around the head and eye. Without specific instruction, drivers have a tendency to shy away from the point probe, or to move to assist the researcher in capturing various trunk points. Landmarks on the head were digitized first, so that any subsequent movements by the driver would not affect the accuracy of those points.

Data Analysis

The data from this study are being used in conjunction with data from a laboratory study with a larger number of drivers (2). In the laboratory study, 63 men and women selected their preferred driving postures under a wide range of cab configurations spanning the dimensions of the vehicles used in the current study. The laboratory data have been analyzed to develop statistical models to predict the postures of drivers with various body sizes. The primary limitation of the laboratory data is that, without actually driving, the participants may not have selected a realistic posture. In particular, the visual demands of driving may lead to different driver-selected seat heights in vehicles than in the laboratory.

Care must be taken in comparing data from in-vehicle studies to prediction models based on laboratory data. The models predict the average posture (eye location, seat position, etc.) expected for a person of a particular body size in the specified cab configuration (steering wheel position, seat height, etc.). However, the data analysis demonstrates that people with the same primary body dimensions (stature, sitting height, and weight) sit with a fairly wide range of postures. This additional variance is not attributable to anthropometric dimensions (4), but rather reflects individual posture preferences. Consequently, model predictions will always deviate somewhat from the postures observed from individual drivers. An effort to validate the laboratory models using in-vehicle data must focus on (a) bias and (b) residual variance, both of which can be estimated over the entire sample of drivers.

The posture of each driver is compared to the model predictions based on body and cab dimensions. The differences between predicted and observed posture variables (eye location, for example) are assessed across the pool of participants. Ideally, the mean difference (observed minus predicted) is zero. A confidence interval on the mean can be used to assess whether small differences from predicted are significant. A significant bias in the predictive model can be compensated for using a constant offset. For example, previous testing with passenger car drivers showed that seat compression after driving resulted in a 9 mm downward shift in eye location relative to the postures predicted based on laboratory data. The analysis focuses closely on trends in the model-versus-measured discrepancies across body sizes and cabs. For example, is there a greater bias in the prediction of eye locations for short-statured drivers?

The second important factor to assess is residual variance. In the analysis of the laboratory data, the statistical posture prediction models leave some of the variance in the predicted variable unexplained. These residuals are typically normally distributed and can be described by a root-mean-square error (RMSE, or standard deviation of the residuals). The standard deviation of the difference between the observed and predicted variable across subjects is compared to the RMSE from the laboratory study. A close match indicates that the model is accounting for approximately the same proportion of variance for in-vehicle postures as in the laboratory.

DISCUSSION

The procedures used in this study are based on those developed at the University of Michigan Transportation Research Institute for studying vehicle occupant postures. These methods have been demonstrated to produce reliable data that accurately represent prevalent on-road driving postures. Although individuals can select a range of postures when driving, the within-subject variance is considerably smaller than the between-subject variance. Further, the within-subject variance (repeated trials with a single driver) is smaller than the variance among individuals with the same body dimensions. Consequently, making individual measurements of preferred driving posture is adequate to characterize the distribution of prevalent postures and to develop prediction models.

Small-scale in-vehicle studies, such as this one, are inadequate by themselves for generating posture prediction models. Yet, the data from studies with reconfigurable laboratory mockups are also inadequate, because they lack the inherent validity of in-vehicle postures measured after driving. The combination of the two types of studies is necessary to create valid posture-prediction methods for use with human figure models.

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