

## EVALUATION OF FORCE FEEDBACK STEERING IN A FIXED BASED DRIVING SIMULATOR

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Eight participants drove a fixed base simulator using both spring-loaded and force feedback steering wheels. Their route included curves of 100, 200 and 300 radii of curvature, and two freeway style exit ramps that were sloped, banked and had changing radii of curvature. Both mean and variance of lane position were calculated. There were no differences in terms of mean and variance of lane position between the steering wheels when driving on straight road segments. Lane position variance was significantly greater when driving on the 100 meter curves than when driving on the 200 and 300 meter curves. Drivers "hugged" left hand curves more when using the force feedback steering wheel as indicated by their average lane position being significantly more to the left. On the two right hand exit ramps, drivers drove significantly more to the left when using the force feedback steering wheel. Subjects rated the force feedback steering wheel higher in terms of realism, maneuverability, and vehicle control on a post-experiment questionnaire.

### INTRODUCTION

Driver input for vehicle control in fixed-based driving simulators may include visual cues, steering "feel", and sounds. Visual cues include objects in the environment, road signs, the vehicle speedometer, rear view mirrors etc. Rockwell (1972) estimates that drivers receive over 90% of information input via vision. Steering "feel" includes the forces generated by power steering and vibrations from different road surfaces. Gordon (1966) found that after vision, steering "feel" was rated the next highest source of input for drivers. Sounds relevant to vehicle control may include tire screeching and the sirens of emergency vehicles. There has been little research on how sounds interact with vehicle control.

We investigated driving control by comparing spring-based steering "feel" with that generated by force feedback (using a torque motor). If vehicle control is equivalent under these conditions, then both types of steering may be used in driving simulators. This would result in lower cost driving simulators being available for driver training and licensing.

Liu and Chang (1995) conducted experiments on force feedback steering in a fixed-based driving simulator. They found no differences in the mean variance of steering wheel angle when drivers drove with no-torque and torque based steering systems on curves of 30, 45 and 60m radii. However, for the straight segment immediately following the sharpest curve (30m), performance was better (less variance of steering wheel angle) when using the torque steering wheel. Differences between the torque and no-torque conditions decreased as a function of trials. This indicates that drivers quickly adapted to the no-torque condition.

Liu and Chang also found that the variance of steering wheel angle was significantly larger for the no-torque condition when drivers were recovering from a skid. Since steering force-feedback is dependent on lateral tire friction and lateral acceleration, it is reduced when a vehicle is in a skid. When force-feedback was available immediately after the skid, drivers were better able to control the vehicle.

Segel (1964) found that the amount that the amount of steering torque was more sensitive to passing maneuvers than when driving on steady-state turns. When the torque gradient was low, drivers had difficulty positioning the wheel.

### METHODOLOGY

#### Participants

Eight male subjects between the ages of 23 and 36 participated in the study. Subjects had 20/20 or corrected to 20/20 vision. All subjects had at least two years driving experience. For participating in the study, subjects were paid a \$10 honorarium.

#### Apparatus

Northeastern University's Virtual Environments Driving Simulator was used for data collection. It provided a 57 degree horizontal field of view via a 7ft. 11in. by 6 ft. screen as shown in Figure 1. The participant's eye was 11 feet in front of the screen.

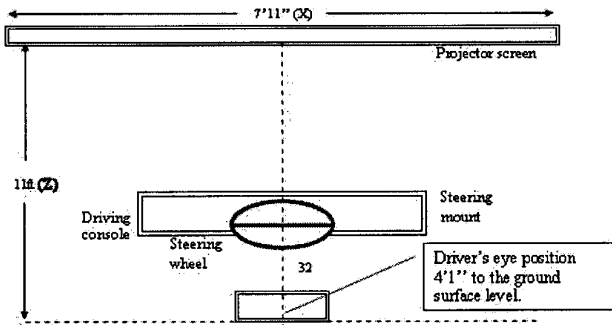


Figure 1. Simulator configuration.

The driving console was the cab of a 1989 Dodge Caravan with the original gas and brake pedals. The steering column was modified to permit installation of one of two steering wheels – spring-loaded or force feedback. The spring-loaded steering wheel was a Madcatz Andretti wheel with a proprietary digital processor that provided up to ten times the speed and resolution of "ordinary analog wheels". It has 220 degrees of rotation. The force feedback steering wheel was a Microsoft Sidewinder which had 210 degrees of rotation. The vehicle dynamics model used is detailed in Pan (2001). Torque forces were calculated from the vehicle dynamics model and programmed using DirectX 7.0. Java 3D was used to generate the three-dimensional virtual environments and control the simulator. The screen resolution was XGA (1024 x 768) and frame rates were in excess of 60 frames/second. A 3D scene is shown in Figure 2.

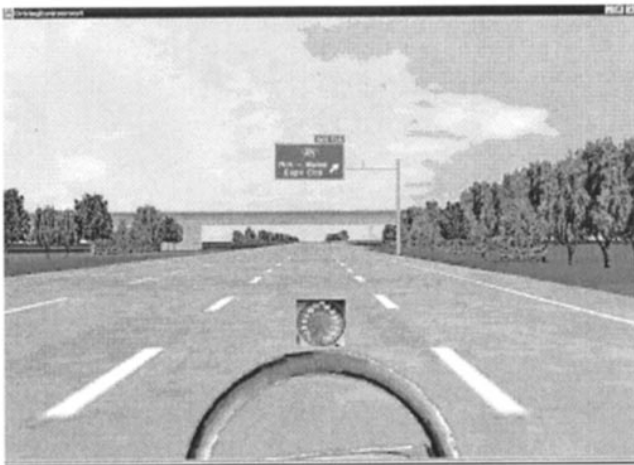


Figure 2. Driving scene.

**Procedures**

Subjects drove a three minute pre-test driving route twice (once with the spring loaded steering wheel and once with the force feedback steering wheel) to become familiar with the vehicle's handling characteristics.

There were two driving environments, curvy roads and freeway (with two exit/entrance ramps). The inclination of the ramps was 1.9 degrees and the ramps were banked 2.5 degrees to the right. The curvy road environment consisted of eleven curves of 100 meter radius, one curve of 200 meter radius, and three curves of 300 meter radius. Each environment (curvy or freeway) was driven by each subject twice – once with the force feedback steering wheel and once with the spring loaded steering wheel. The order of the four runs was counterbalanced among the eight subjects.

Subjects were instructed to drive at about 55 mph or slower where appropriate (traversing curves and exit/entrance ramps), and to stay in their own lane. As shown in Figure 2, a speedometer was superimposed on the road ahead. Each run took about 3 to 4 minutes to drive. During the run, the subject's vehicle lane position and vehicle velocity were recorded seven times a second for future analysis. After each run, subjects completed a short questionnaire on the vehicle's handling characteristics.

**RESULTS**

Lane position was scaled from 0 to 10, where 0 indicates the right most position in the lane and 10 indicates the left most lane position. Figure 3 shows the variance of lane position as a function of curve radius. Two-sample F-tests showed the variance for the 100m curve was greater than that at 200m ( $p < 0.036$ ) and greater than that at 300m ( $p < 0.042$ ). No other differences were statistically significance.

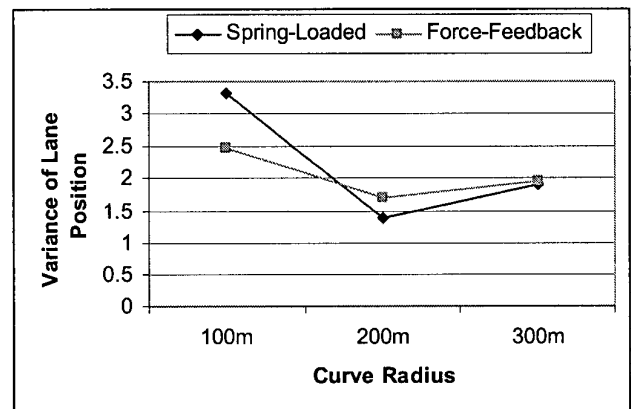


Figure 3. Variance of lane position when driving on curves.

Figure 4 shows the average lane position when driving on straight roads. Paired t tests indicated no significant difference between driving with the spring loaded and force feedback steering wheels. The lane position variances when driving on straight roads were also not statistically different between the steering wheels.

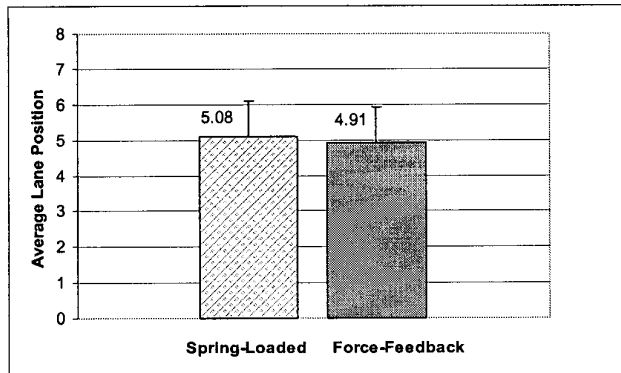


Figure 4. Average lane position when driving on straight roads (means and standard error displayed).

The average lane positions when driving the left (6 curves) and right (5 curves) 100 meter curves are shown in Figure 5.

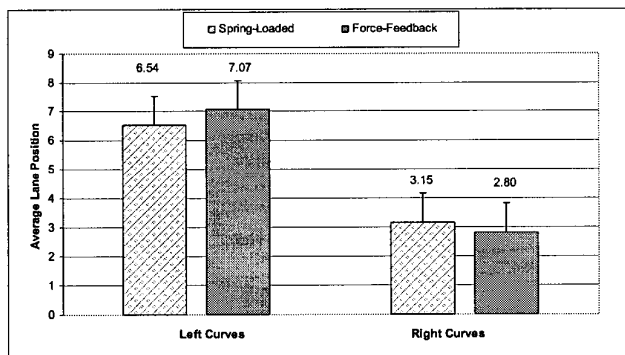


Figure 5. Average lane position when driving on curves (means and standard error displayed).

As expected, drivers drove to the right-side of the road on right-hand curves and to the left-side of the road on left-hand curves. By means of a paired one-tail t-test, the mean lane position using the force feedback steering wheel on the left curves was significantly higher ( $p < 0.037$ ) than when using the spring loaded steering wheel. Thus, when on a left curve and using force feedback steering, drivers hugged the left side of their lane more than when using spring loaded steering. When driving on right curves, average lane position between steering wheels was not significant. Variances of lane position by curves and type of steering wheel were not statistically different.

The two exit ramps were curved to the right. Figure 6 shows the average lane position with the data from the downward sloping and upward sloping exit ramps combined.

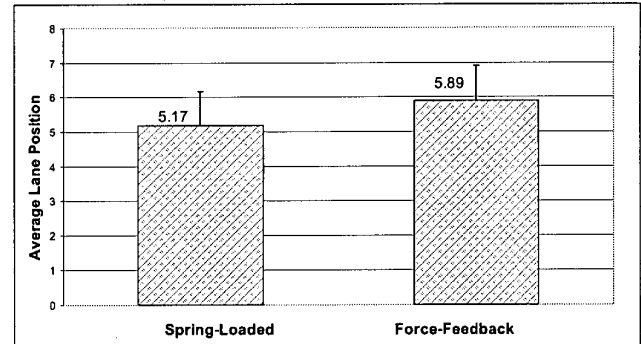


Figure 6. Average lane position when driving on exit ramps (means and standard error displayed).

A one-tailed paired t-test determined that the difference of the means was statistically significant at  $p < 0.008$ . This indicates that when driving on exit ramps that curved to the right, drivers stayed farther to the left in their lane using the force feedback steering wheel as compared to the spring loaded steering wheel. Differences in lane position variance when driving on the exit ramps were not statistically different.

Question 7 on the questionnaire was "Were you able to maneuver over the exit ramp?". A 1 was associated with "not at all", and a 5 with "with ease". The average score when driving with the force feedback steering wheel was 3.62 versus 3.39 when driving with the spring loaded wheel.

Question 4 on the questionnaire was "Rate the difficulty in maneuvering the car with the steering wheel". A 1 was associated with "difficult" and a 5 with "easy". The average score when driving with the force feedback steering wheel was 3.80 versus 3.36 when driving with the spring loaded wheel.

Question 6 on the questionnaire was "Did the steering have good control over the vehicle?". A 1 was associated with "not at all", and a 5 with "well controlled". The average score when driving with the force feedback steering wheel was 4.06 versus 3.63 when driving with the spring loaded wheel.

Table 1 shows the average driver ratings for the remaining questions. On all the questions, average driver ratings were better or higher when driving with the force feedback steering wheel.

Table 1  
Average Driver Ratings For the Post-Questionnaire

Question	Spring Steering	Force Feedback
1. Did you feel like you were driving a real car? 1-not at all 5-totally	3.25	3.24
2. How did you find steering the driving simulator compared with steering a real car? 1-not comparable 5-very realistic	3.12	3.38
3. Rate your sense of real-time response to the steering wheel. 1-noticeable delay 5-no delay	3.91	4.19
5. How realistic was the steering experience? 1-not at all 5-totally	3.31	3.35

**DISCUSSION**

Liu and Chang (1995) used variance of steering angle to measure vehicle control while the present study used variance of lane position. They found variance of steering angle decreased as a function of increasing radius of curvature for both the torque and non-torque conditions. Our Figure 3 suggests this same trend when variance of lane position is used as the dependent variable. We found no difference between spring-based steering and force feedback steering when driving on curves. Thus variance of either steering wheel angle or variance of lane position is not sensitive to the presence or absence of steering force feedback while driving on curves.

We found average lane position to be a more sensitive measure than variance of lane position. The finding that drivers “leaned into” the direction of curves was based on average lane position. Surprisingly the amount of leaning into left-hand curves was significantly greater when force-feedback steering was used as compared to spring-based steering. Does this indicate that drivers had more confidence when driving on curves with force-feedback steering than spring-based steering? Drivers using force feedback steering also “leaned into” right-hand curve more than drivers using spring-based steering, but this difference was not statistically significant.

However, a different phenomenon was found on the right-hand curved exit ramps that were also sloped. Here drivers did not lean into the right-hand curves. Drivers who

used force-feedback steering were significantly more to the left of the center of the lane than drivers who used spring-

based steering. Does the fact that the exit curves were banked to the right mean have something to do with this?

Differences between force feedback and non force feedback steering appear to occur in difficult driving situations. Liu and Chung found differences when recovering from a skid and the present study found difference on sloped exit ramps that were banked. In both studies no differences were found when driving on straight roads or gentle curves. Further research is needed to systematically study the value of force feedback in difficult driving conditions.

From the post-experiment questionnaire, subjects rated the force feedback steering as better in terms of realism, maneuverability and control of the vehicle. It is clear that the subjects had a better feeling and felt more immersed with force feedback steering than with spring based steering.

As shown by Question 7, the force feedback steering system was rated high when traversing the exit ramps. Since the exit ramps were sloped, had positive or negative elevation changes, and non constant radii of curvature, they may be considered the most difficult to steer. Thus, exit ramps revealed the benefits of force feedback steering.

**REFERENCES**

Gordon, D. A. (1966) Experimental Isolation of Drivers' Visual Input. *Public Roads*, 33, 53-68.

Hoffmann E. R. and Joubert P. N. (1968) Just Noticeable Differences in Some Vehicle Handling Variables. *Human Factors*, 10(3), 263-272.

Liu, A. and Chang S. (1995) Force Feedback in Stationary Driving Simulator. CBR TR 95-1, Nissan Cambridge Basic Research Center, Cambridge, MA, USA.

Pan, Y. (2001) A Real-World Computationally Efficient Vehicle Dynamics Model. Masters Thesis, Department of Mechanical, Industrial, and Manufacturing Engineering, Northeastern University.

Rockwell, T.H. (1972) Skills, Judgment and Information Acquisition in Driving, In Human Factors in Highway Traffic Safety Research, (T. W. Forbes, Editor), John Wiley & Sons, 133-164.

Segel L. (1964). An Investigation of Automobile as Implemented by a variable-Steering Automobile. *Human Factors*, 1964, 6, 333-341.