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THE EFFECT OF LATERAL MOTION CUES DURING SIMULATED DRIVING

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ABSTRACT

The vast majority of driving simulators currently in existence do not include motion systems. When motion systems are present, they are often too small to reasonably represent the forces experienced in an actual car. Nevertheless, simulators with little or no motion are routinely used to characterize driver behavior and safety. The underlying assumption is that measures of driving performance such as lane violations or heading errors are valid indicators of relative driving performance even in the absence of motion cues. Ford's Research & Advanced Engineering group operates a driving simulator called VIRTTEX (VIRtual Test Track Experiment) that has enough motion capability to realize lateral scale factors between 0.50 and 0.70 during non-emergency driving. This simulator has been used to compare both driving and vehicle performance measures during simulated driving at various levels of the lateral scale factor.

Results from two experiments are presented. In the first experiment an event detection protocol was used to measure the level of distraction induced by various in-vehicle tasks such as hand-held or hands-free cellular phone operation. Forty-eight adult drivers participated in the study with the VIRTTEX motion system set to a lateral scale factor of 0.6. Six additional test participants experienced the same protocol with only vertical motion feedback.

In the second experiment, 24 test participants were asked to follow closely-spaced cones while executing a controlled lane change at constant forward speed. They were instructed to follow the path marked by the cones as closely as possible. Runs were repeated with lateral scale factors of 0.00, 0.25, 0.50 and 0.70. Results from both experiments are analyzed to determine the effect of lateral motion cues on driving performance measures.

BACKGROUND

Driving simulators that have little or no motion cueing capability have routinely been used to study the distracting effects of in-car devices [1,2,3]. These studies compare measures of driving performance (e.g., brake reaction time, standard deviation of lane position, lane violations) while drivers are engaged in various secondary tasks. Poor performance while engaged in a secondary task is evidence of interference between the secondary task and the primary driving task. To extrapolate these findings to actual driving requires that the effects measured in the fixed simulation laboratory carry over to the more complex driving environment in a straightforward way. The usual assumption is that the absolute level of any given performance measure may be different in the fixed simulation than in actual driving, but that the relative magnitude of effects will remain unchanged.

Previous research by Bray, performed in both flight and helicopter simulators points to the possibility of interactions between motion cueing and primary task demand [4,5]. The general observation is that motion cues are much more important when vehicle control is difficult. For driving simulators, McLane [6] showed that motion cues significantly affect driver performance, but later work by Repa [7] indicated that relative rankings of vehicle properties remain unchanged. Neither study addressed the possibility that secondary task rankings might change with motion cueing. Furthermore, both McLane and Repa's studies, were carried out on a simulator with extremely limited motion capabilities and the question of motion scale factor was not addressed.

The experiments presented in this paper attempt to quantify the effect of motion cueing on lateral performance measures during driving that includes external disturbances. The research was undertaken to shed light on two questions that must be clearly understood in order to correctly interpret much recent simulator research:

1. Are there interactions between motion cueing and the types of secondary tasks typically studied when evaluating the distraction caused by in-car devices?

2. What level of motion cueing is required for drivers to minimize errors during lateral maneuvers?

VIRTTEX

Both experiments presented here were conducted on Ford's VIRtual Test Track Experiment (Figure 1 and Figure 2), a large, 6 degree-of-freedom (DOF) moving base driving simulator. VIRTTEX is designed to accommodate a full-size, interchangeable vehicle cab. Vehicles as large as a full-size SUV can be accommodated but for the current experiments a 2000 Ford Taurus was used. The cab includes a steering control loader for accurate feedback of road and tire forces to the driver.

VIRTTEX uses a front-projection display system. The display surface is a spherical section with a radius of 12ft. A high-gain (4.5:1) coating has been used to ensure brightness and contrast. Five Cathode Ray Tube projectors present the driving scene on the display surface. Three projectors in the forward field of view cover 180° x 39° and two rear projectors cover 120° x 29°. Each channel is driven from a PC-based image generator running at a fixed rate of 60Hz. All five channels currently have a resolution of 1600x1200 pixels each.

The VIRTTEX motion system is a hydraulically powered six-DOF hexapod. The motion system allowed sufficient movement to support lateral scale factors up to 70% in the experiments described here. This was possible because of the relatively large motion envelope of the VIRTTEX motion system (Table 1).

Figure 1 The VIRTTEX simulator

Figure 2 Typical VIRTTEX cab and road scene

	Accleration	**Velocity**	**Displacement**
Longitudinal/Lateral	**>0.6g**	**>1.2 m/s**	**±1.6m**
Vertical	**1.0g**	**1.0 m/s**	**±1.0m**
Pitch/Roll	**> 200 deg/s^2**	**>20 deg/s**	**±20deg**
Yaw	**> 200 deg/s^2**	**>20 deg/s**	**±40deg**

Table 1 VIRTTEX motion envelope

MOTION CONTROL IN VIRTTEX

The VIRTTEX driving simulator is controlled by using an unusually flexible Motion Drive Algorithm (MDA) [8]. To control lateral motion, the VIRTTEX MDA implements both a traditional frequency-splitting algorithm that relies on tilt-coordination or a position algorithm that directly feeds vehicle lateral accelerations into the simulator lateral channel. These algorithms are referred to as 'classical' and 'positional' and can be selected at run-time or even changed while a simulation is in progress to meet experimental needs.

The classical algorithm can make more efficient use of the simulator workspace by substituting platform tilt for low-frequency accelerations. The positional algorithm uses the lateral position of the vehicle center of gravity (CG) relative to the roadway as its input for all frequencies. This algorithm only uses tilt-coordination to provide lateral accelerations not accounted for by the lateral movement of the vehicle relative to the roadway (typically acceleration in curves). The positional algorithm is generally more accurate than the classical. It is also more robust because its behavior does not directly depend on the frequency of its lateral inputs. As long as the frequency content of the motion is high enough that the vehicle remains on the roadway, the algorithm will function properly.

In the experiments described in this paper, both algorithms were used. The first experiment, on the effect of motion cues while using cellular telephones, was run with the classical MDA. The second experiment, the effect of motion on lateral control, used the positional MDA.

A key feature of both the classical and the positional MDA is that accelerations that are calculated by the VIRTTEX vehicle model can be reduced by a scale factor before motion cueing begins. For example, a lateral acceleration scale factor of 50% would mean that the MDA would only attempt to reproduce half of the acceleration that would be experienced during the corresponding maneuver in an actual car. These scale factors are usually determined by the size of the motion envelope and the type of maneuver to be performed. Scale factors are adjusted to the largest value possible while remaining within the motion envelope of the simulator.

A fixed-base simulator can be modeled as a limiting case of a motion simulator where the scale factors associated with all the degrees of freedom have been set to zero. A common situation is for an essentially fixed simulator to have a small amount of vertical vibration presented to the driver to give the illusion of riding over non-smooth pavement. This case is easily modeled by setting all scale factors to zero except for the vertical motion channel.

EXPERIMENT 1: EFFECT OF MOTION CUES DURING CELLULAR TELEPHONY

VIRTTEX has been used to quantify distraction in drivers caused by in-vehicle tasks including the use of cellular telephones. A very brief description of the experiment follows. A more complete description can be found in [9]. After the experiment was completed, six additional test participants drove the protocol with an altered motion control calibration. For these six subjects, only vertical motion feedback was provided. The scale factors for all other motion channels were set to zero. Although the test participants did experience vertical vibrations associated with road roughness, this condition will be referred to as 'fixed' or 'fixed base' in the sections that follow. Time and budget constraints limited this part of the experiment to only six test participants.

Distraction Protocol

In the main portion of the experiment, 48 adults drove on a simulated section of a US interstate during daylight conditions on dry road. The simulated road was topographically mapped from a section of actual interstate along I-94 in Michigan. Lane widths, lane divisions, elevation changes and road curvature all match the actual roadway. Drivers were instructed to drive in the right lane only and to follow a lead vehicle at a self-selected 'safe following distance'.

In addition to road roughness, random wind disturbances affected the driver's car. These wind gusts were designed to cause heading errors that would require the drivers to make corrections to avoid lane violations. Without steering input from the driver a lane violation would occur in approximately 4 seconds when driving on a straight section of roadway.

Each driver wore a commercially available hands-free headset during the drive. The headset was only used during the hands-free tasks listed below. The nomenclature used to refer to each secondary task in the rest of the paper is given next to the task name in parenthesis:

3. **Radio Tuning (radio):** This involved using only the TUNE rocker switch on the radio to locate a specified FM radio station.

4. **Climate Control Adjustments (hvac):** For this task, the participant was asked to adjust the fan speed up one setting, the temperature dial to the maximum heating position, and the directional dial to the defrost setting.

5. **Incoming calls (incHF or incHH):** The driver was instructed to answer incoming phone calls using the hand-held or hands-free cellular phones while driving. After the caller identified who they were and why they were calling, the driver was instructed to tell the caller that they could not talk at the moment because they were on the road. At this point they were instructed to end the call. Hands-free (HF) calls were answered by pressing the phone button located below the rearview mirror. Hand-held (HH) calls were answered by picking up a commercial hand-held phone munted on a holder near the center stack.

6. **10-digit dialing (dialHF or dialHH):** The dialing task always took place prior to the voicemail interaction and was used to access the voicemail server before beginning the voicemail retrieval task described below. In the hand-held case the driver would pick up the phone from its holder and dial each digit manually. No memory presets or other dialing shortcuts could be used. In the hands-free case the driver would press the phone icn on

the mirror. The driver would then speak the phone number and be connected to the voicemail server. The task ended as soon as the voicemail server connection was established.

7. **Retrieving and responding to voicemail (vmHF and vmHH):** The driver was prompted to retrieve a voicemail message from a specific person using either the hand-held or hands-free phone. The act of dialing into the voicemail server was timed and recorded separately and is considered part of the dialHF or dialHH tasks. After connecting to the server the driver would use the phone buttons (vmHH) or voice commands (vmHF) to login to the server and find the message and listen to it. Each message asked the driver for some simple piece of factual information (e.g. home address, model year of the driver's personal car, etc.). The driver would then use the voicemail system to reply to the message and leave the requested information as an attached voicemail.

For all of the results reported in [9], the VIRTTEX motion system was active and was programmed with a classical motion drive algorithm. The lateral acceleration scale factor was set to 0.6 for the duration of the drive.

Effect of motion

The small number of test participants in the no-motion case (n=6) and the between-subjects nature of the comparison, limits the conclusions that can be drawn from the data. Nonetheless, some effects are striking. Figure 3 shows the number of lane violations per trial for each secondary task in the full-motion case and in the fixed case. A lane violation was considered to have occurred when a tire on the driver's vehicle was completely outside of a lane boundary. The secondary task labeled 'none' corresponds to driving while no secondary task is in progress.

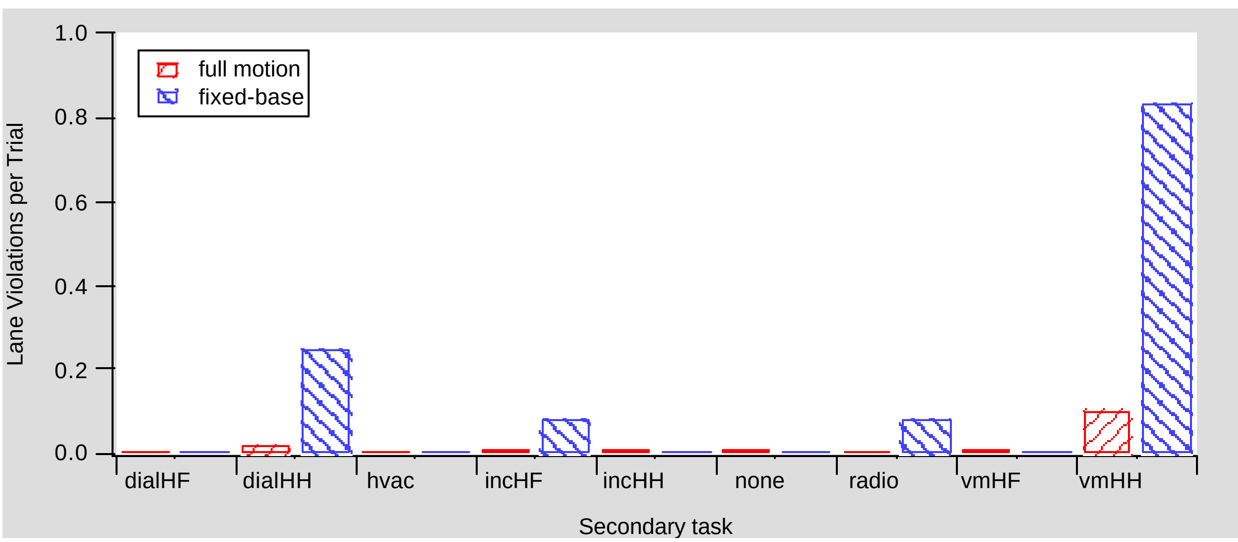

Figure 3 Lane violations

An analysis of variance (ANOVA, Table 2) shows both a main effect for the presence of motion (FIXED$) and an interaction with the type of secondary task (CAT$). For purposes of the ANOVA, the radio and hvac tasks have been combined in a traditional task grouping ('trad'), the hands-free tasks have been combined into a single grouping ('hands free'), and the hand-held tasks have been likewise combined ('hand held'). Driving with no secondary task has been labeled 'norm'.

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
CAT$	5.451	3	1.817	23.162	0.000
FIXED$	1.112	1	1.112	14.180	0.000
FIXED$*CAT$	3.351	3	1.117	14.240	0.000
Error	74.758	953	0.078		

Table 2 ANOVA table for lane violations during simulated driving

The nature of the interaction term is shown in Figure 4. Lane violations for the hand-held tasks increased substantially when lateral motions cues were not present. Lane violations in the other cases did not increase.

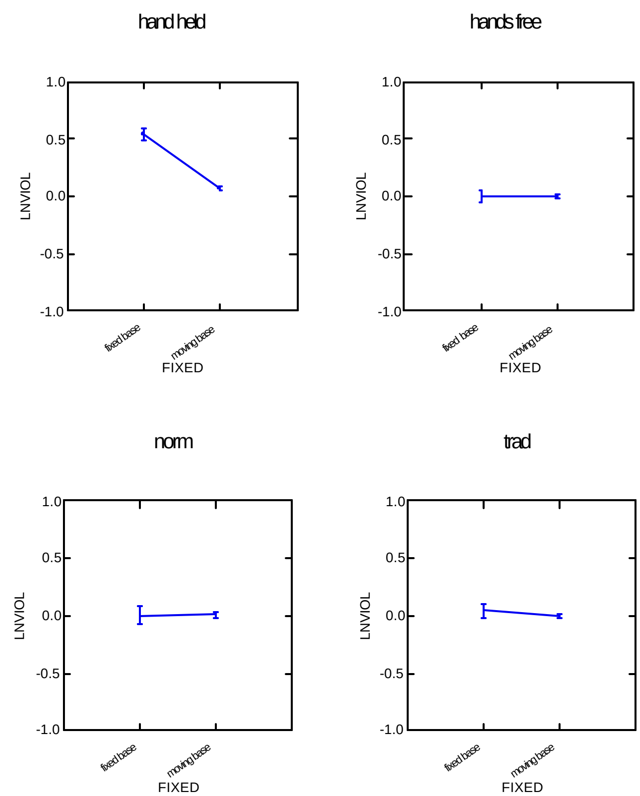

Figure 4 Secondary task ⊗ motion condition interaction for the number of lane violations per task

Another measure of vehicle control is the vehicle heading error. Heading error is defined as the difference between the instantaneous roadway tangent and the current vehicle heading measured in degrees. There are many ways to summarize this measure over a given secondary task performance. We can choose an average value, a peak value, a median and so on. Averages tend to discount the effect of a momentary, severe error and peak values give too much weight to such disturbances. The summary statistic analyzed here is the 90th percentile heading error denoted HE90. The value of HE90 computed over any secondary task is the value of heading error that was exceeded 10% of the time. It is more sensitive to large transient errors than an arithmetic mean but not as sensitive as a peak value.

Figure 5 shows the effect of motion cues on heading error.

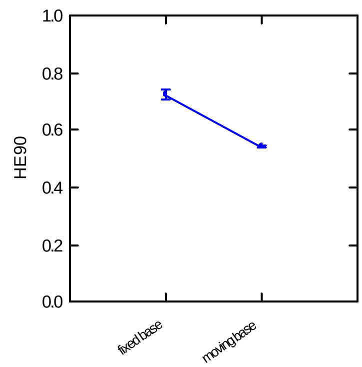

Figure 5 90th percentile heading error (degs) by motion condition

Not surprisingly, heading errors are larger in the fixed case. Just as for the lane violation measure, we also find an interaction between secondary task type and motion condition. The ANOVA results are shown in Table 3.

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
CAT$	2.502	3	0.834	32.235	0.000
FIXED$	2.581	1	2.581	99.758	0.000
FIXED$*CAT$	0.680	3	0.227	8.763	0.000

Table 3 ANOVA table for 90th percentile heading error during simulated driving

The interaction effects are shown in Figure 6. The hand-held and traditional tasks show a much larger increase in heading error than normal driving or the hands-free tasks when lateral motion cues are removed.

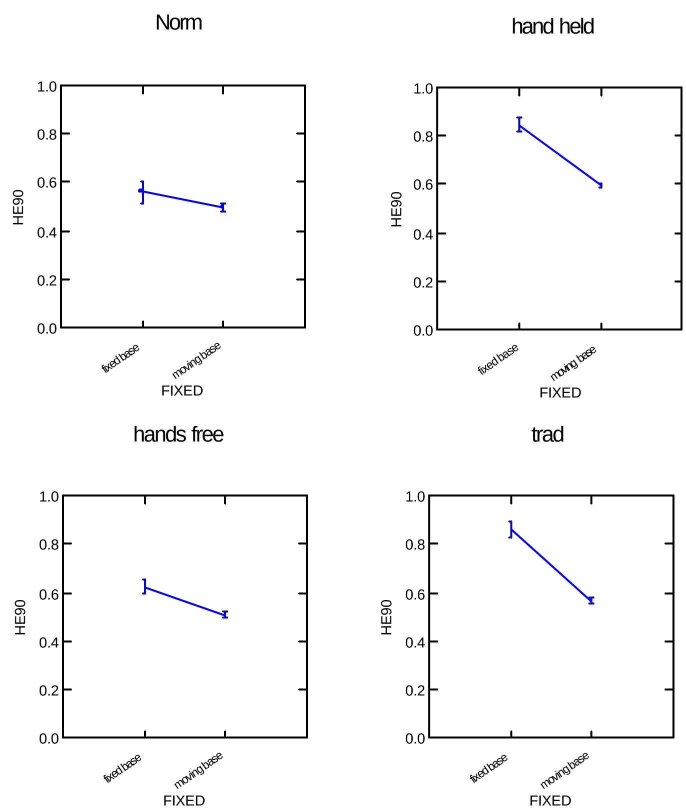

Figure 6 Secondary task ⊗ motion condition interaction for 90th percentile heading error (degs)

The presence of an interaction between secondary task type and motion cueing is potentially troublesome for studies that use measures of vehicle lateral control as an indication of secondary task disturbance. The results presented here suggest that such measures will lead to different conclusions depending on the motion cueing available in a given simulator. The tasks that lead to the smallest interaction term are hands-free communication and no secondary task at all. These are tasks that make little or no additional demand on the driver's visual attention. Tasks that have higher visual demand appear to be more profoundly influenced by the presence or absence of lateral motion cues.

This type of interaction is not surprising given the nature of fixed-base simulation. Because fixed simulators provide no lateral motion cueing, they force driver's to over-allocate visual attention to maintain lane position and heading. Secondary tasks that require an additional allocation of visual attention are competing for an already over-extended resource and therefore show a substantial interference with the primary driving task.

A simulator with realistic motion cues may allow the driver to achieve a more natural balance of attentional allocation between visual and vestibular cues for lateral control and lane tracking. Additional visual demand can be compensated in some measure by the vestibular cues and the resulting interference of visually demanding tasks with lateral control is diminished.

EXPERIMENT 2: EFFECT OF MOTION CUES ON VEHICLE HEADING CONTROL

The goal of this experiment was to quantify the effect of lateral motion scale factor on a driver's ability to reject disturbance during a lateral tracking task. The results in the previous section indicate that motion cues, most likely lateral motion cues, play a large role in a driver's ability to maintain lane position. However, the large disparity between the number of subjects in the motion case (n=48) and the fixed case (n=6) is unsatisfactory from a statistical point of view. This time 24 test participants drove a virtual world that consisted of a straight, flat roadway, that was 9.5ft wide.

Experimental Design

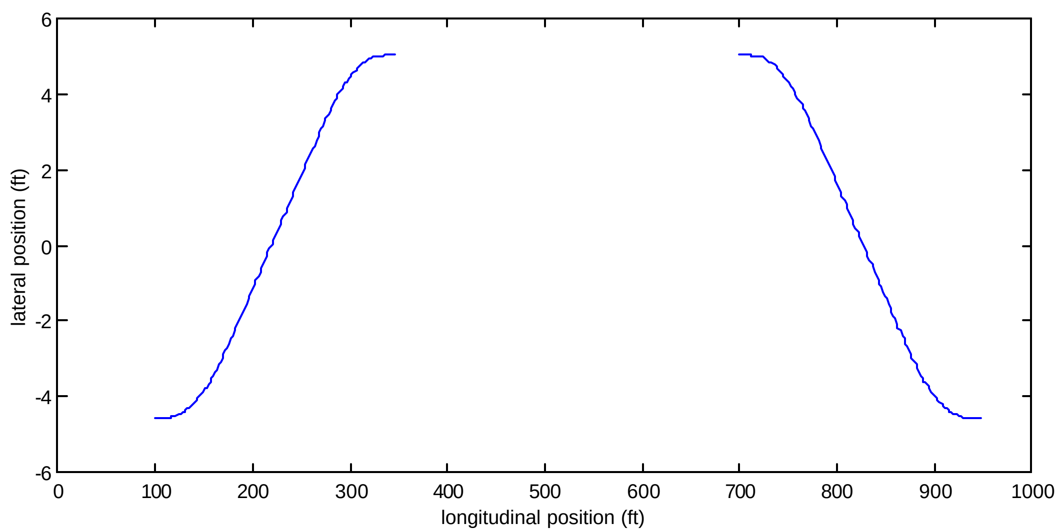

Figure 7 Centerline of the maneuver cones

Cones were placed on the roadway that defined a path from right to left and then from left to right. The centerline of the cones is shown for two maneuvers in Figure 7. The cones were place on the roadway in pairs with a 9.5ft lateral separation. They were spaced every 12.5ft longitudinally. A gap of 350ft separated each cone set during the main experimental blocks.

The test subjects used cruise-control to maintain a forward vehicle speed of 60mph. They were instructed to maneuver through the cones without hitting them with the vehicle. The VIRTTEX simulator cab had an approximate lateral width of 6ft. Trials were arranged in 4 blocks of 24 maneuvers each. Each block consisted of 8 training maneuvers and 16 disturbance-rejection maneuvers.

During the 16 disturbance-rejection maneuvers in each experimental block, a 2 second wind gust was applied to the vehicle. The wind speed formed a pulse as shown in Figure 8. The wind was applied parallel to the lateral axis in the body frame of the vehicle. The wind gust always began as the vehicle entered a section of cones, but the sign of the wind gust and the peak magnitude varied from trial to trial. The four allowable wind disturbances had peaks of –55, -25, +25, and +55 mph. Each condition was repeated during the disturbance rejection blocks so that the design has 2 replicates per condition.

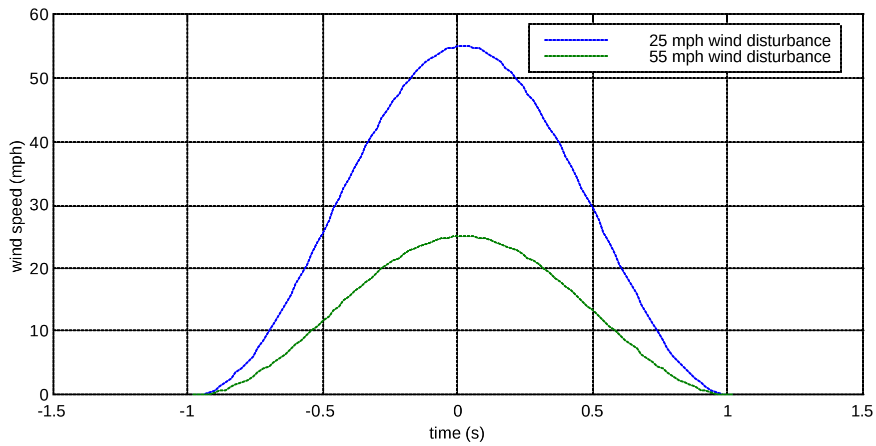

Figure 8 Lateral wind disturbances

The lateral scale factor was held constant during each 24-trial block. The levels chosen were 0%, 25%, 50% and 70% (70% is the largest practical scale factor available in VIRTTEX for the maneuvers described). The scale factor for the yaw channel was adjusted to the same level as the lateral scale factor because of the close coupling between the lateral and yaw channels. Typical lateral accelerations for the 3 non-zero scale factor cases are shown in Figure 9.

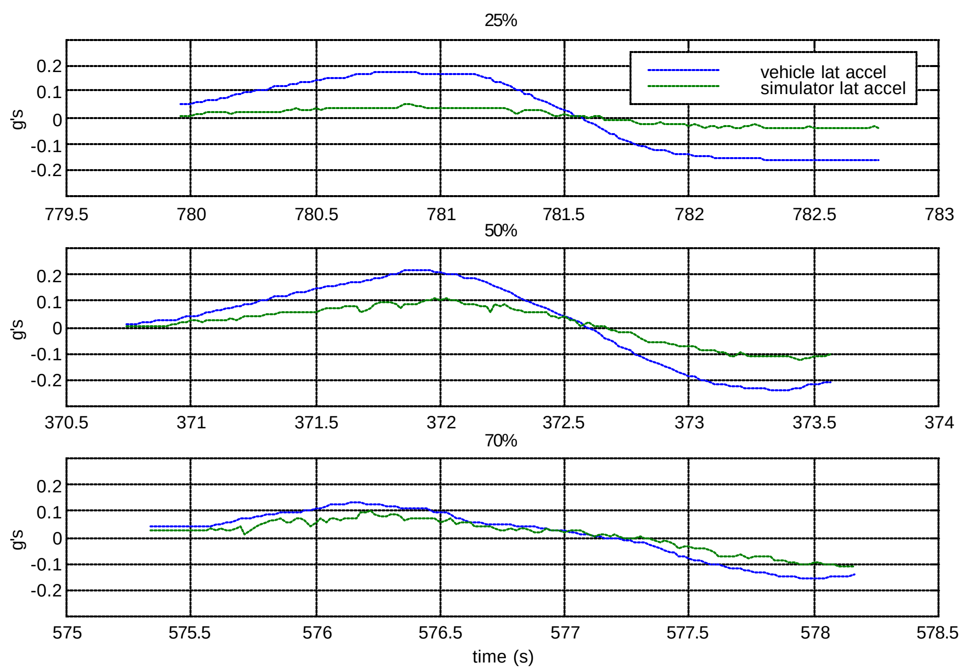

Figure 9 Typical lateral accelerations at 25%, 50% and 70% scale factors

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Each of the 24 test participants experienced a different ordering of the four scale factors. Order effects likely occurred during the experiment, but these were not analyzed. Instead the effect of order was removed by averaging the results over all possible orderings using an ANOVA procedure. The experiment was analyzed as a within-subjects design using univariate procedures with test subject treated as a random factor. The experimental factors are summarized in Table 4. Test replications are considered part of the error term. The subjects ranged in age from 19 to 62 . No attempt was made to balance the test population for age or gender.

Factor	*Levels*	*DOF*
Subjects	24	23
Scale Factor	0%, 25%, 50%, 70%	3
Wind Direction	Left, Right	1
Wind Speed	25mph, 55mph	1

Table 4 Experimental design

Post-Maneuver Errors

It became clear during the experiment that test subjects sometimes experienced large path errors immediately after exiting the cones. These errors were not random but appeared to be associated with scale factor. Figure 10 and Figure 11 show paths for the same subject during a trial with identical 55 mph wind disturbances. During the maneuver in Figure 10 the scale factor was 0% and during the maneuver in Figure 11 the scale factor was 70%. A large underdamped path oscillation is apparent at 0% scale factor that is either absent or critically damped at 70% scale factor. However, the test subjects were given no special instructions about minimizing path error after they had left the cones.

It is not possible to know if the test participants would have changed their control strategies if they had been instructed to maintain a path down the lane center after they had exited a maneuver. However, it seems clear that scale factor is playing a role in increasing the effective yaw damping when exiting the cones. In the analysis that follows, measures will be computed over two intervals. The first interval will correspond exactly to the time that the center of gravity of the vehicle was inside the cones. The second interval will extend this time by 2 seconds to capture some of the post-maneuver behavior.

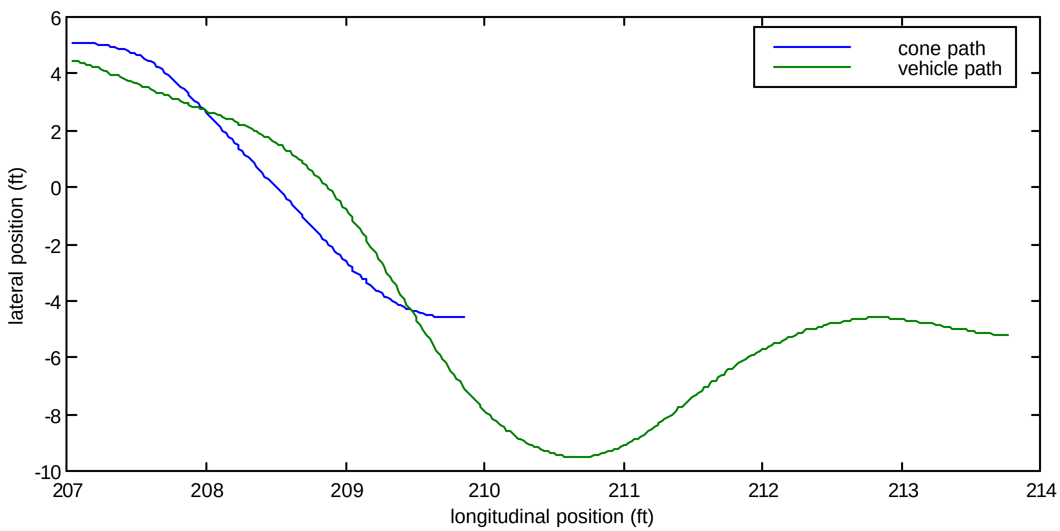


Figure 10 Post-maneuver path for subject 4, scale factor = 0%

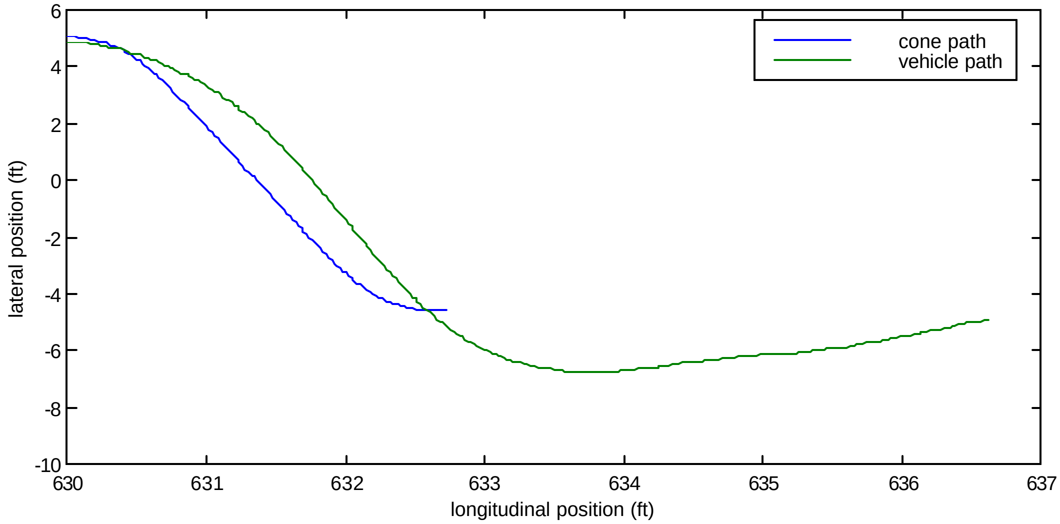


Figure 11 Post-maneuver path for subject 4, scale factor = 70%

Measures of lateral control

Two measures of lateral control were computed for each trial. The first measure was the RMS (root-mean square) heading error comp uted over the trial interval. The heading error (also referred to as yaw error) is defined as the difference between the instantaneous vehicle yaw angle and the heading angle of the cone path center. The second measure was the RMS path error. The path error was defined as the difference between the lateral position of the vehicle CG and the lateral position of the cone path center. Each of the measures was computed over the interval when the vehicle was in the cones and over an interval extended by two seconds as discussed above.

Each measure was analyzed using an ANOVA model of the same form:

```
measure = CONSTANT + SUBJ+SF+WDIR+WSPEED+DIR+WDIR*WSPEED+DIR*WDIR+SUBJ*SF
```

Table 5 lists the terms that appear in the model and in the subsequent analysis.

Term	Definition	
Measure	The dependent measure. One of:	
	YAWERR	RMS yaw error (deg)
	YAWERR2	RMS yaw error computed over the trial interval extended by 2 seconds (deg)
	RMSPATH	RMS path error (ft)
	RMSPATH2	RMS path error computed over the trial interval extended by 2 seconds (ft)
SUBJ	The test participant (subject) number	
SF	Lateral scale (and yaw) scale f actor. One of 0%, 25%, 50% or 70%	
WDIR	Wind direction. Either left or right.	
WSPEED	Wind speed in mph. One of 25mph or 55 mph.	
DIR	The direction of the maneuver. Either left or right.	

Table 5 Definition of ANOVA model terms

Analysis of YAWERR

The results of the ANOVA for YAWERR are shown in Table 6. All the included model terms are significant at the $p<0.05$ level. In addition to scale factor, the test subjects are a significant factor. The wind speed is also an important factor, since the size of the disturbance is much larger at 55 mph than at 25 mph. Perhaps surprisingly, the direction of the maneuver is significant, albeit at a very small level. The wind speed and direction interaction reflects the fact that wind gusts in the direction of turning are more disruptive than gusts opposing the intended direction.

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SUBJ	12.452	23	0.541	8.244	0.000
SF	20.217	3	6.739	102.618	0.000
WDIR	6.218	1	6.218	94.682	0.000
WSPEED	42.821	1	42.821	652.068	0.000
DIR	0.855	1	0.855	13.019	0.000
WDIR*WSPEED	0.461	1	0.461	7.018	0.008
DIR*WDIR	7.119	1	7.119	108.400	0.000
SUBJ*SF	6.055	69	0.088	1.336	0.037
Error	94.235	1435	0.066		

Table 6 YAWERR ANOVA table

For the YAWERR measure only, the full set of effects plots are presented in Figure 12 through Figure 19. In these figures, YAWERR is expressed in degrees. For subsequent measures only the SF effects plot will be shown. Significant differences between the plots presented for YAWERR and other measures will be noted in the text.

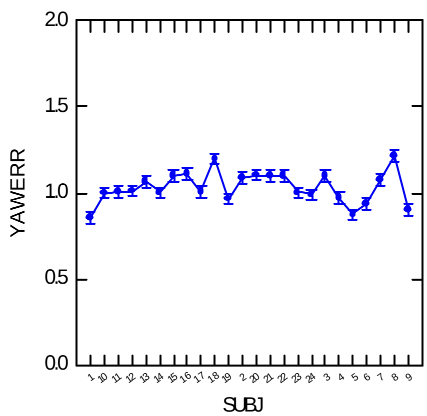


Figure 12 Subject main effects

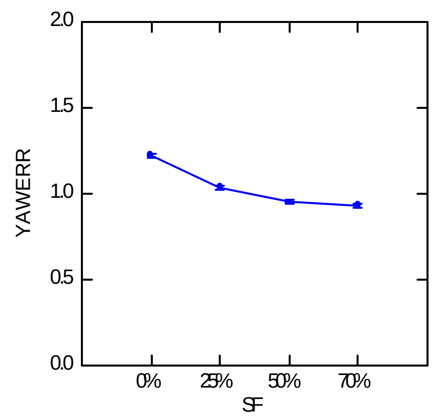


Figure 13 Scale factor main effects

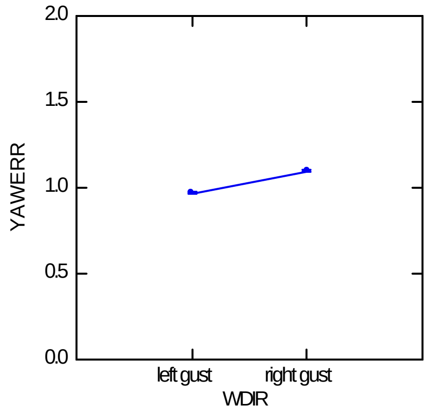


Figure 14 Wind direction main effects

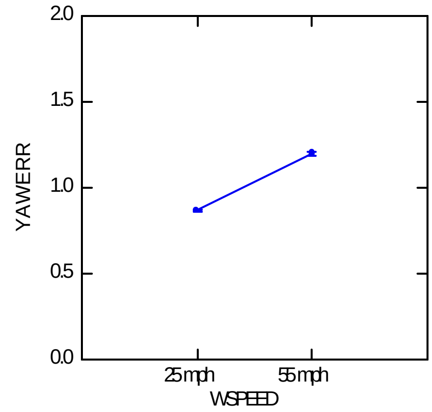


Figure 15 Wind speed main effects

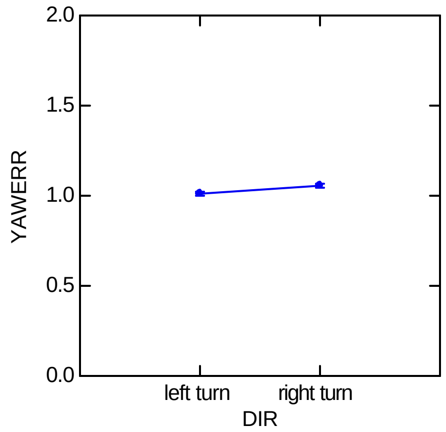


Figure 16 Maneuver direction main effects plot

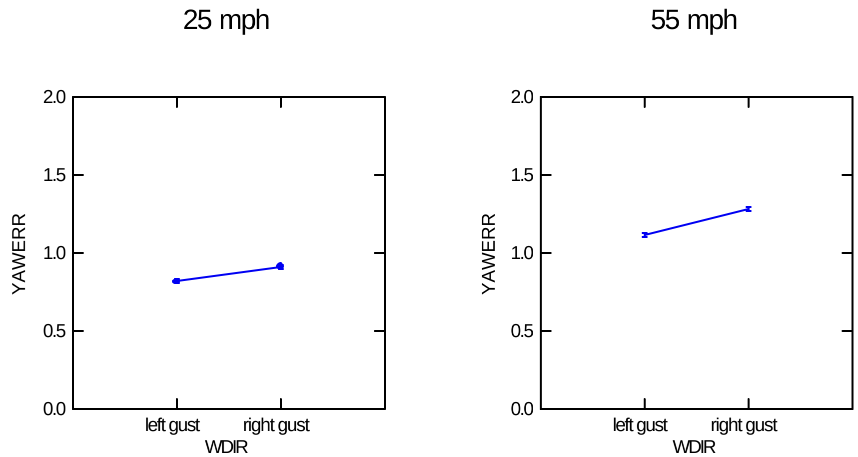


Figure 17 Wind direction ⊗ wind speed interaction

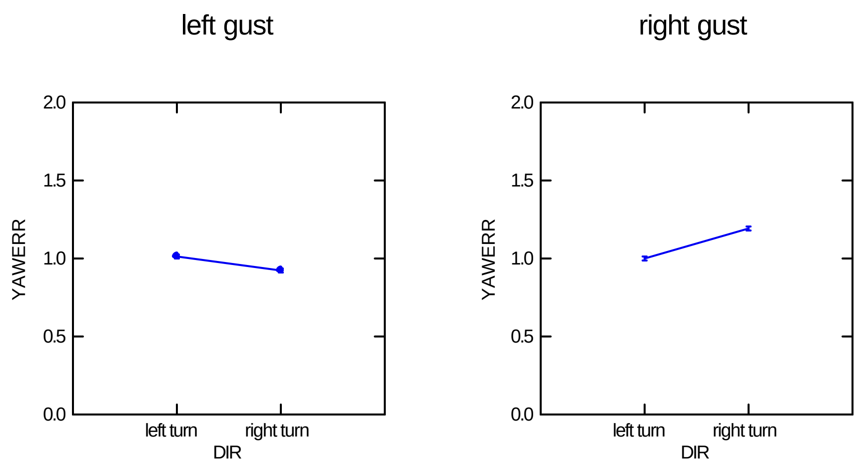


Figure 18 Wind direction ⊗ maneuver direction interaction

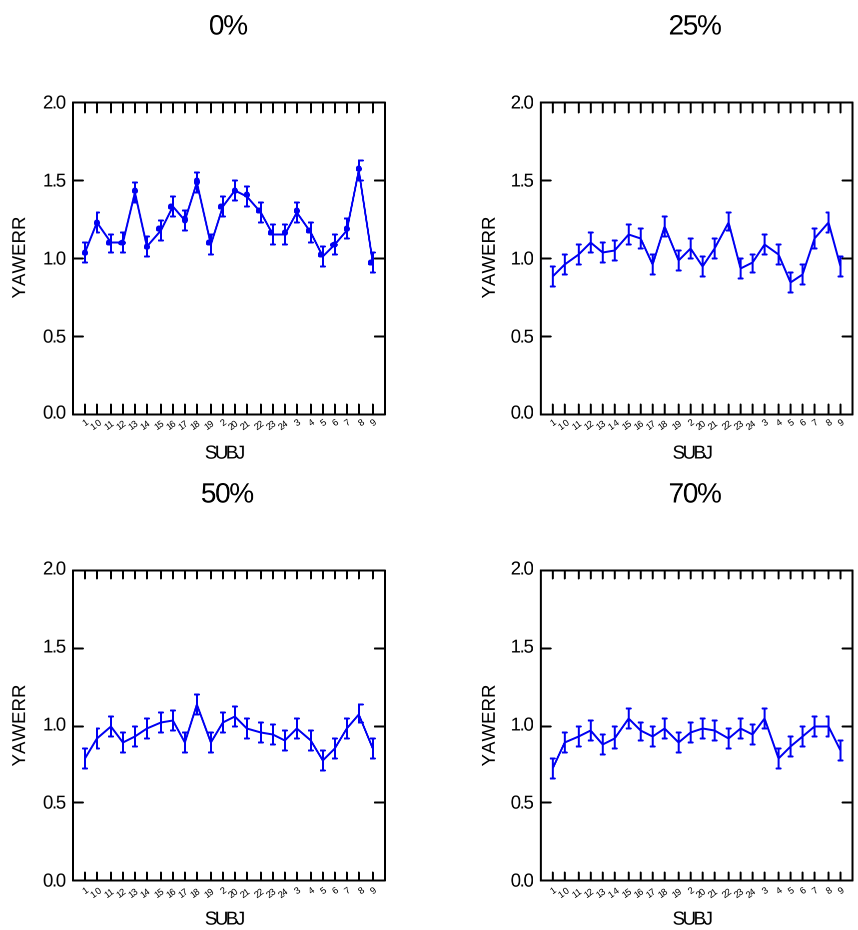


Figure 19 Scale factor ⊗ subject interaction

Each reduction in YAWERR as scale factor increases is significant up to 50% scale factor. The difference between 50% and 70% is not significant at the $p< 0.05$ level as can be seen in Table 7. The reduction in YAWERR variability as scale factor increases is also noteworthy. A histogram of the YAWERR values makes the reduction in variability more readily apparent in Figure 20[1].

```
Using MSE of 0.088 with 69 df.
Matrix of pairwise mean differences:

                         0%          25%          50%          70%
              0%          0.000
             25%         -0.186       0.000
             50%         -0.271      -0.084       0.000
             70%         -0.290      -0.104      -0.020       0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

                         0%          25%          50%          70%
              0%         1.000
             25%         0.000       1.000
             50%         0.000       0.001       1.000
             70%         0.000       0.000       0.792        1.000
```

Table 7 Comparison of scale factor levels

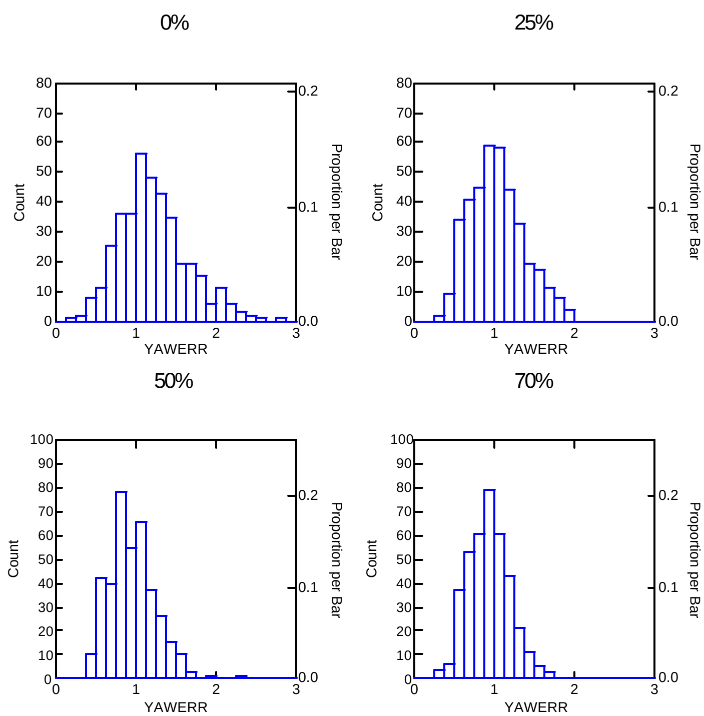


Figure 20 Yaw error variability

Analysis of other lateral control measures

Extending the measurement interval to include two seconds immediately following the traversal of the cones does not change the character of the yaw error effects. Figure 21 plots the main effects for YAWERR2, the RMS yaw error computed over the extended interval in degrees.

[1] The change in standard deviation with mean level violates the homogeneity of variances assumption implicit in the ANOVA. However, these data have also been analyzed using a square root transformation to stabilize the variance with no change in the results.

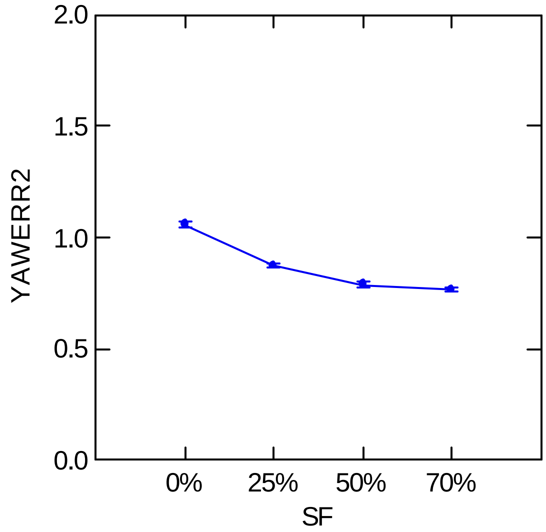
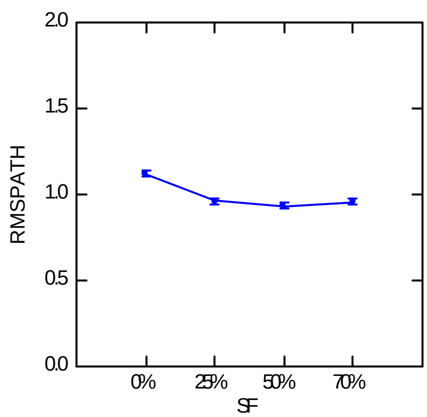


Figure 21 YAWERR2 main effects

The analysis of PATHERR does show a difference between the values computed in the trial interval and the extended interval.



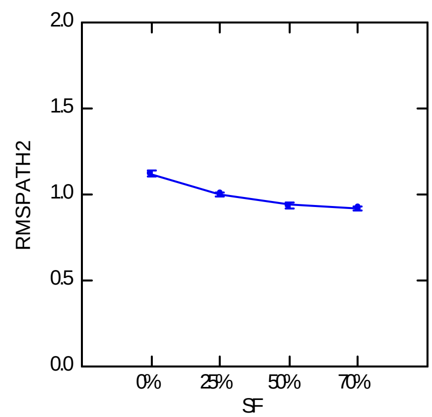


Figure 22 RMS path error (ft)

Figure 23 RMS path error over the extended interval (ft)

Figure 22 shows the path error decreasing at the 25% scale factor, but leveling off after that. The 25%, 50% and 70% scale factors are not different fromone another at the $p<0.05$ level. In contrast the path error computed over the extended interval (Figure 23) looks much like the heading error – showing a monotonic decrease in error with scale factor.

DISCUSSION

The two experiments presented in this paper show that the presence of motion cues can have a significant effect on vehicle control when disturbances are present. In general, control errors are largest when motion cues are absent from the simulation. Heading control appears to be more sensitive than path following measures, perhaps because heading errors that are corrected quickly are prevented from growing into large path errors. This implies that drivers need to allocate more attention to heading control when motion cues are absent or substantially reduced in order to maintain acceptable levels of tracking error.

The possibility that motion cues play a role in attentional allocation for drivers is further suggested by the presence of statistically significant interactions between motion cueing and secondary task type. The implications of these interactions for the widespread and growing use of fixed-base simulators to measure distraction caused by secondary tasks are serious. A common rationale for using these simulators is that, while results may not be comparable to actual driving in an absolute sense, relative comparisons of performance metrics across secondary task type are still meaningful. The interactions presented in this paper imply that such relative comparisons are specific to the motion cueing environment provided by the simulator.

It will require further research to determine the degree of motion cueing required to eliminate these interactions. However, the results of the disturbance rejection trials presented in this paper suggest that lateral and yaw motion scale factors of approximately 50% may be sufficient to allow drivers to minimize heading errors during lateral maneuvers resulting in a more natural balance between visual and vestibular attention.

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