THE EFFECT OF MOTION CUEING ON SIMULATOR COMFORT, PERCEIVED REALISM, AND DRIVER PERFORMANCE DURING LOW SPEED TURNING

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Abstract - The purpose of this work is to verify the ability of the General Motors Research driving simulator motion system to:

- Mitigate simulator induced discomfort felt during high yaw rate turning maneuvers such as those experienced while turning in an intersection
- Improve subjective rating of fidelity and objective performance measures

A pilot study was conducted to measure the effect of limited displacement and 1:1 yaw motion cues on simulator induced sickness, perceived realism, and driver performance. Three levels of motion cues (No-motion, Hexapod/No-Yaw, Hexapod/ 1:1 Yaw) were manipulated. Dependent measures included subjective assessment of realism of the simulated vehicle; self-reported discomfort; and objective measures of driver input and vehicle response.

Results indicate that the current configuration of the driving simulator is effective in generating motion cues to improve driver performance during intersection turning. For simulator sickness and realism, however, we did not find any statistical effect of motion cueing.

Key words: driving simulator, yaw table, motion cueing, driver behavior, simulator sickness.

1. Introduction

Up to recently, most of the driving simulator studies conducted at General Motors Research (GMR) utilized highway driving scenarios which were not problematic with respect to simulator discomfort, but new investigations increasingly require lower speed maneuvers such as those found in parking or city driving scenarios. As a result of this, there has been a marked rise in simulator discomfort incidents.

Some recent studies indicate that providing a large displacement yaw degree-of-freedom may provide some benefit in driving simulation during low speed driving maneuvers such as turning at intersections. Maurant and Yin [Mau1] demonstrated that a turning cabin reduces optical flow during turns and theorized this accounted for the reduced simulator discomfort measured when compared to a similar turning condition in a non-moving cabin. Similarly, Yoichi and Nobuyuki [Yoi1] found reduced simulator discomfort and improved driver sighting behavior during intersection turns with a rotating cabin compared to the fixed-base condition. Yamaguchi et. al. [Yam1] found lowered position and directional variability with a turning cabin in a slalom maneuver, and Hogema et. al. [Hog1] concluded large yaw motion improves driver behavior as well as realism during low speed turning.

In an attempt to improve participant comfort for these types of maneuvers, a motion system was implemented at GMR with a unique motion and visual system design combination incorporating a large yaw displacement capability. The design consists of a full vehicle cabin mounted on a small displacement hexapod which is supported by a large displacement yaw table. The motion system is centered within a 12 foot diameter projection screen.

The intent of this pilot work is to refine a study design to measure the effect of the GMR driving simulator (GMRDS) motion system cue capability on induced sickness, perceived realism, and driver performance. This pilot manipulates three levels of simulator motion cues (No-motion, Hexapod/No-Yaw, Hexapod/1:1 Yaw) experienced by test participants while recording dependent performance and subjective measures.

2. Prior literature

Recent published studies provide mixed results regarding the effects of driving simulator motion cueing on simulator study participants. Although these studies are difficult to aggregate because of differences in each study's simulator design, the study purpose, conditions explored, and methodology used; they do provide evidence that it is possible to measure effects of motion on perceived realism of the simulated vehicle response, induced simulator sickness, and driver performance.

2.1. Perceived realism

Most studies investigating perceived realism have concluded that realism is enhanced with motion. When perception is integrated from multiple sensory channels it provides a more accurate perception of the real world environment [Sto1]. Essential to this is that the simulator must accurately correlate motion cues with the visual and auditory systems to effectively convey the proper experience to the user [Ber1].

In a study comparing four motion conditions while driving a curved road at a constant speed, an effect was demonstrated on perceived sense of simulator realism [Dam1]. Additionally, an investigation on the effect of motion control algorithms on vehicle following behavior yielded a result that all study participants felt the motion conditions provided a higher degree of realism in the simulated vehicle response than the no-motion condition [Col1]. Furthermore, another study found an effect of motion on subjective assessment of realism while steering into and out of a curve, accelerating and braking [Wen1]. Lastly, an investigation was conducted on detection thresholds for roll tilt coordination. One of the findings was that supra-threshold roll ~~rates~~ levels were judged as more realistic [Nes1]. However, in a research study using two levels of yaw motion in lane change and 90 degree turning maneuvers, no effect from yaw motion was found for realism [Hog2].

2.2. Induced sickness

Simulator sickness has an adverse effect on human behavior and can yield outcomes such as dizziness, fatigue or nausea. The most widely accepted explanation is that simulator induced sickness (SIS) is created from the mismatch between received sensory messages to those that are expected through experience [Rea1], although this theory has exceptions [Bos1].

Visual cueing alone, such as in fixed-based simulators, can induce sickness [McC1]. The addition of motion cues is thought to improve this condition. However, even advanced motion-based simulators can lead to sickness if the visual information does not correspond to the information induced on the vestibular system [Cas1].

Recent studies conducted to evaluate motion cues and their effect on simulator sickness have had varying results. In a comparison of similar studies conducted on Ford Motor Company's fixed based and motion simulators, a lower incidence of simulator discomfort (measured using Kennedy's simulator sickness questionnaire, SSQ) was reported for participants in the motion-based simulator as compared to those driving the fixed-based simulator [Cur1]. Another investigated the effect of yaw motion on driver assessment of induced sickness using a questionnaire administered before and after participants drove right and left turns. It was found that drivers reported higher degree of comfort in the yaw motion condition [Mou1]. It was further found that subjective reports of simulator discomfort decreased in turns for participants in a turning cabin as opposed to a fixed based cabin [Asa1].

Other studies, however, have not achieved a reduction in simulator sickness with the presence of motion. For example, when studying yaw and no-yaw motion in a lane change and 90 degree turning maneuvers, no effect was found for the level of simulator sickness [Hog1]. Additionally, an investigation including a motion sickness evaluation given at the beginning and end of a city circuit consisting of four 90 degree turns yielded no effect for induced sickness. Moreover, Wentink et. al. found that the classical motion algorithm control condition rated lower than the rumble-only condition [Wen1].

The measurement of simulator sickness in the referenced studies seems problematic for several reasons. The effect of simulator design characteristics on SIS is a confounding factor. Secondly, Kennedy has found that at least 40% of participants had never reported any sickness symptoms [Ken1]. As such, these participants don’t provide an effective population for inclusion in a study on SIS. A similar point can be made for the type of driving task used in a discomfort study; a non-demanding task (such as freeway driving) may not provide enough stimulus to induce discomfort.

On the other hand, using extremely sensitive subjects, or an extreme task would induce carryover effects from one condition to the next; or worse, lost/excused subjects. The ideal situation in terms of experimental efficiency, is using a subject who is slightly sensitive to discomfort symptoms, does not adapt to the discomfort response, and a simulated driving task that is only demanding enough to induce minor discomfort.

Lastly, the statistical methods used on Kennedy’s SSQ scores are debatable. In this paper we conducted nonparametric analysis on percentile scores. In contrast, most prior studies treated the scale variable of the raw scores as a continuous variable, which may be problematic.

2.3. Driver performance

Performance measures are crucial to provide a quantitative assessment of driver capability and the qualification of vehicle systems. The addition of motion cues has been shown to improve driver performance, however, not all studies support this finding.

One study assessed the contribution of motion during braking and cornering maneuvers [Sie1]. This study found that during braking, motion cueing resulted in lower deceleration rates as compared to a no-motion condition. Braking behavior was also stabilized in contrast to the no-motion condition where drivers modified/adapted their braking behavior over time. The authors also found that longitudinal motion resulted in lower mean velocities and that lateral motion had an effect on lateral lane position for the maneuvers investigated.

An additional report contained two experiments exploring the effect of motion cues on specific performance measures used for in-car device evaluation [Gre1]. In the first experiment drivers operated radio, climate control, and telephone features while driving on a typical interstate road and steering against a disturbance function. In this experiment, interaction effects were noted for lane violations and a heading error metric between motion and vertical vibration conditions. In the second experiment, subjects drove four motion conditions while conducting a lane position change and regulating against a disturbance function. Heading and path error was higher in the No-motion condition. Interestingly, the effect of motion diminished for some motion levels, indicating partial motion may be as efficient as full in terms of effect.

Further studies noted difference in driver performance measures during an intersection turning maneuver. Drivers had lower steering, yaw rate, lateral acceleration, mean speed, and braking levels when yaw cueing was present [Hog1].

An equal number of recent studies, however, found that motion cues have no effect on driver performance. One study which investigated motion effects during curve negotiation with a steering disturbance showed no significant difference between motion conditions on the driver's performance measures [Dam1]. Another investigation that studied the effect of motion on vehicle following behavior found no effect on driver performance measures [Col1]. Additionally, no effects of motion cues on driver performance were obtained on intersection and curve negotiation, braking, or acceleration behaviors [Wen1].

2.4. Summary and hypothesis

Although each study discussed above was different in many ways (i.e. apparatus, study purpose, conditions explored, and methodology), most found evidence of an effect of motion on perceived realism. Fewer studies found evidence to indicate that motion cueing lowers simulator induced sickness, while only half of the referenced studies found evidence of an effect of motion on driver performance measures.

In summary, there is evidence supporting a role of motion cueing in improving perceived realism and driver performance, and in reducing simulated induced sickness. Some inconsistency in the literature may be attributed to shortcomings in methodology.

The GMRDS has a design configuration that:

- Separates the projection system and screen from the motion system, thereby eliminating mass and providing opportunity for high bandwidth motion response in a small space
- Stacks the hexapod on a yaw ring to reduce complexity of kinematic control and potential cueing artifacts because the rotational dynamics are isolated from hexapod translations
- Provides 1:1 driver yaw motion without using the image generator to rotate the virtual road image. This produces a smoother rendering of close road objects that are rotating with respect to the driver. The four meter projected image distance from the driver's eye essentially displays the road scene at infinity for comfortable driver eye convergence and accommodation

To examine the effect of motion cueing on perceived realism, induced sickness and driver performance, we applied three levels of motion (No-motion, Hexapod/No-Yaw, Hexapod/1:1 Yaw). We hypothesized that:

- Participant comfort will be improved by providing large yaw motion during low speed cornering over a no-yaw condition
- Limited displacement motion will improve perceived realism over a no-motion condition
- Both motion conditions will show an effect on the obtained performance measures compared to a no-motion condition

The following provides the methodology and results of a pilot study conducted to explore measuring the benefit of the motion system utilized in the GMRDS.

3. Apparatus

The GMRDS provides 360x30 degree roadway view to the driver located in a modified full vehicle compartment as shown in Fig. 1. Haptic feedback is provided at the pedals and steering controls by a three channel control loading system.

Fig. 1. Driving simulator (access door in cab exchange position).

The vehicle compartment is located on 7 DOF motion system that consists of a limited displacement hexapod mounted on a large displacement yaw table as shown in Fig. 2.

Since prior publication [Ber2] provided a description of the GM simulator (with the exception of the motion system), the following will only provide an explanation of the motion system.

Two important reasons for adding motion capability in the simulator were to:

- Reduce incidence of simulator discomfort for large amplitude directional maneuvers by providing realistic cab yawing motions to complement visual cues

- Enhance “realism” for the driver by providing higher bandwidth onset cueing motions related to the vehicle’s response to driver control inputs

Fig. 2. Hexapod and yaw table.

Maneuvers that may be enhanced by the addition of yaw motion include those with lower speeds and higher yaw rates such as maneuvering at intersections. The addition of a yaw table makes possible large scale rotations that will allow 1 to 1 scaling of the yaw motion for almost all practical maneuvers. The selected yaw table provides ±175 degrees of yaw motion at rates up to 60 degrees/second. A bearing ring mounts directly to the facility foundation, and carries the load of the hexapod and cab.

For a typical turn or maneuver, the graphic image remains stationary (in yaw) on the screen while the cab and the yaw table rotate. If, at the end of the turn or maneuver, the yaw table position is too close to exceeding its excursion limit, the graphics and yaw table can be gradually rotated back to center position. Knowledge of the roadway and maneuvers to come are used to modify and optimize the washout process and reduce unnecessary re-centering motions.

The hexapod subsystem is used to provide only onset acceleration cues and ride feel to the driver. This makes it particularly suitable for on-center lane regulation. Since the hexapod only supports the cab and driver, and not a yaw table, projectors and screens, it can be substantially smaller and/or higher frequency response per unit of energy. The actuators have a 190 mm stroke and, based on the geometry of the upper and lower attachment triangles, the achieved 6 DOF motion is about ±200 mm in translation, and approximately ± 6 degrees in rotation. Yaw motion can be provided either through the yaw table or hexapod, separately and independently. For purposes of this study, hexapod yaw was turned off and all the yaw motion was provided by the yaw table.

4. Methodology

There were two independent factors; motion and driving session. The three conditions of motion were No-motion, Hexapod/No-Yaw (consisting of 0.5 scale for pitch & roll accelerations but no-yaw, and 0.5 scale for surge & lateral translation accelerations with traditional washout within the motion envelope), Hexapod with Yaw table (same translational and rotational settings as in the prior condition but with ±180 degrees of yaw).

Twelve subjects with equal gender distribution, drove 3 times in a factorial design with random order for conditions as shown in Table 1. To reduce carryover effects from prior motion condition, subjects received 24 hours of rest between unique condition drives. This was done for all but two subjects who for convenience, waited only 4-6 hours between two of the conditions.

The drive task consisted of two road segments, one segment had two intersection turning maneuvers, a left turn followed by a right turn; the other segment had two traffic circle maneuvers, a straight and a 45 degree diagonal turn (The measured total transport delay for these scenarios was 67±5ms). There was a 5 minute rest between segments.

The drive task was balanced for order such that for half the drives, subjects experienced the intersection segment first and the other half received the traffic circle segment first. The route was selected from a prior and convenient drive scenario and thus not particularly created for this study as shown in Fig. 3a-b.

Lateral and longitudinal motion was present during the Hexapod motion conditions with classical washout filters, but no tilt coordination. High frequency vibration generated by the sound system subwoofer and shaker drivers (mounted on structure under seat and engine compartment) was present in the driving compartment for all conditions relating to engine r.p.m.

Table 1. Study condition order.

Subject# and Gender	Motion Condition Day 1	Motion Condition Day 2	Motion Condition Day 3
S1 male	No-motion	Hexapod/ No-Yaw	Hexapod/ 1:1 Yaw
S2 female	Hexapod/ No-Yaw	Hexapod/ 1:1 Yaw	No-motion
S3 male	Hexapod/ 1:1 Yaw	No-motion	Hexapod/ No-Yaw
S4 female	No-motion	Hexapod/ 1:1 Yaw	Hexapod/ No-Yaw
S5 male	Hexapod/ No-Yaw	No-motion	Hexapod/ 1:1 Yaw
S6 female	Hexapod/ 1:1 Yaw	Hexapod/ No-Yaw	No-motion
S7 female	No-motion	Hexapod/ No-Yaw	Hexapod/ 1:1 Yaw
S8 male	Hexapod/ No-Yaw	Hexapod/ 1:1 Yaw	No-motion
S9 female	Hexapod/ 1:1 Yaw	No-motion	Hexapod/ No-Yaw
S10 male	No-motion	Hexapod/ 1:1 Yaw	Hexapod/ No-Yaw
S11 female	Hexapod/ No-Yaw	No-motion	Hexapod/ 1:1 Yaw
S12 male	Hexapod/ 1:1 Yaw	Hexapod/ No-Yaw	No-motion

Dependent measures were position and velocities for steering, accelerator and brake pedal control; lane deviation, speed, yaw rate, and subjective ratings for realism and discomfort. Summary statistics for the performance measures were calculated for the road segments 50 feet before and after the apex of the turn maneuvers.

Fig. 3a. Intersection.

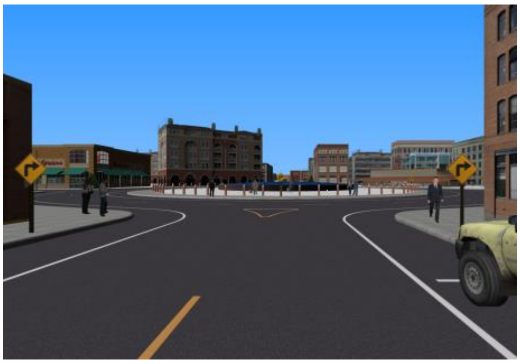

Fig. 3b. Traffic circle.

Participants filled out a baseline SSQ and then received 1 minute of drive training in the simulator driving a two block straight road to familiarize themselves with the simulator speed and steering control tasks. They received the same motion condition they would experience in the test for the up-coming run.

After the familiarization drive participants were then taken outside to drive a real vehicle (compact car). They pulled out of a roadside parking space and drove 15-25 mph to a stop sign, continued for a short distance (1/4-1/2 mile) and turned into a parking lot, turned around and returned to the starting location. This drive lasted about 5 minutes. The real vehicle was identical to the driving compartment used in the simulator.

The simulated vehicle's dynamic response did not correspond to the actual physical vehicle, but represented a crossover type vehicle used in a prior study. Other than the driver eye point difference (a crossover vehicle is higher), it was thought that at the low driving speed there was no practical difference. There was no attempt to replicate maneuvers represented in the simulator test for the real track driven during the real drive (anchoring) period.

After the real car drive, participants were shown the study route using a prerecorded video and instructed where to expect turn locations and the type of directional signs they were to look for and follow. Participants then drove the assigned test segment drives resting between each drive. Participants completed the Kennedy SSQ and simulator realism questionnaire after each drive segment.

4.1. Participants

Twelve employees at General Motors Research were recruited. None had driven the simulator before and all were screened for prior history of motion sickness.

4.2. Kennedy SSQ

The Kennedy enhanced SSQ [Ken1] and the prescribed scoring procedure was used to evaluate simulator comfort levels before and during the course of trial drives.

4.3. Realism survey

A survey was created to assess realism of motion, controller feel, environment and vehicle control in the simulator.
Participants were asked to check a box for each subcategory indicating their opinion using the five point scale corresponding to:

1. Not at all like a real car and the difference is disturbing or bad
2. Different and the difference is weird or odd, not that good
3. Different but the difference is OK, or does not detract in a negative way
4. I'm not sure. I cannot tell a difference from the simulator and a real car
5. This experience is what I think a real car feels like

Realism score for each category was calculated by assigning a number corresponding to the checked box rating for the following categories: Overall sense of Real Driving, Sense of Motion, Road Feel Realism, Car Braking Response, Car Acceleration Response, Forces Felt Turning the Steering Wheel, Brake Pedal Forces, Accelerator Pedal Forces, Controlling the Car in the Lane, Controlling Speed, Visual Scene of Road and Environment, Quality of Sounds Experienced, Seating Comfort, and Air Temperature and Humidity. There was also a comment section for each category for participants to qualify their rating in each category.

5. Analyses and results

5.1. Sickness Questionnaire (SSQ)

Five participants reported at least one symptom in the baseline questionnaire. They were not included in the SSQ data analyses. Composite scores of Nausea (nausea, stomach awareness, increased salivation, burping); Oculomotor (eyestrain, difficulty focusing, blurred vision, headache); Disorientation (dizziness, vertigo) and a total SSQ score were calculated according to formulas developed by Kennedy and Lane (1993). These scores were then transformed to percentiles [Ken1].

All analyses on SSQ data were conducted on the percentile scores. Friedman tests were performed to compare between motion base conditions on each composite score for each segment. None of the tests were significant, *ps* < .20 (see Figure 4 for counts of the percentile scores). However, there is a consistent trend of higher values associated with the traffic circle segment for all composite scores. In contrast, the trend of difference between conditions was less clear.

In general, the two conditions with motion seemed to lead to more severe discomfort.

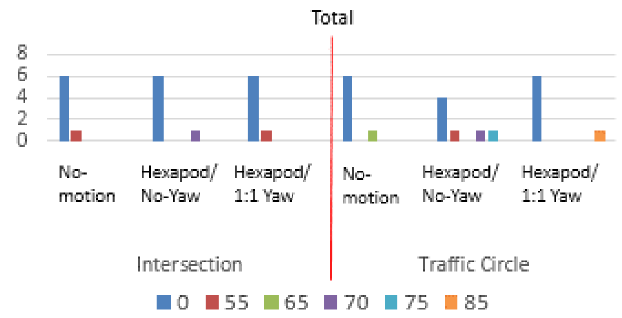

Fig. 4. Counts of percentile scores of SSQ by condition and segment.

For the Nausea and Oculomotor scores, there was a slight trend that the Hexapod/No-Yaw condition resulted in more severe discomfort compared to the Hexapod/1:1 Yaw condition.

In addition, we found a trend of fewer symptoms being reported in the later sessions compared to the first session (see Figure 5), although no statistical analysis was conducted.

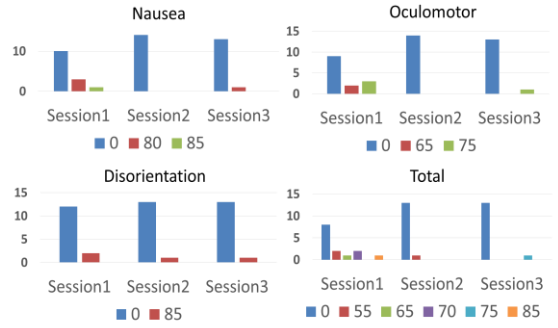

Fig. 5. Counts of percentile scores of SSQ by session.

5.2. Realism questionnaire

Friedman tests were conducted on each item to compare between motion conditions for each segment. Due to missing data, Overall Sense of Real Driving and Quality of Sounds Experienced for the intersection segment and Sense of Motion, Road Feel Realism and Quality of Sounds Experienced for the traffic circle segment had only 11 participants' data included in the analyses. None of these tests reached significance. Two tests were marginally significant, including for Controlling Speed, $S(12)=4.57$, $p=.10$ and Car Acceleration, $S(12)=5.21$, p=.07. Participants rated the two motion conditions higher than the No-motion condition for Car Acceleration, indicating they experienced a higher sense of acceleration in these motion conditions. Controlling Speed was rated lower in the motion conditions, indicating they felt less velocity control in the motion condition (see discussion).

Participants were asked to also provide comments while rating realism categories. An assignment of positive or negative tendency was made (i.e. if words like "too sensitive", "not good" or "bad" were mentioned the comment tendency was labeled negative, if positive words like "good" or "better" were used, the comment was labeled positive).

The No-motion, Hexapod/No-Yaw, and Hexapod/1:1 Yaw conditions generated 81, 74, 66 individual comments, respectively. A contingency analysis on the assigned tendency was performed using Pearson Chi Square test which showed a significant difference for condition p< .0001, a post hoc test was not performed. The corresponding mosaic plot is shown in Fig. 6 and indicates a proportionally higher number of negative comments were associated with the No-motion condition compared to the others.

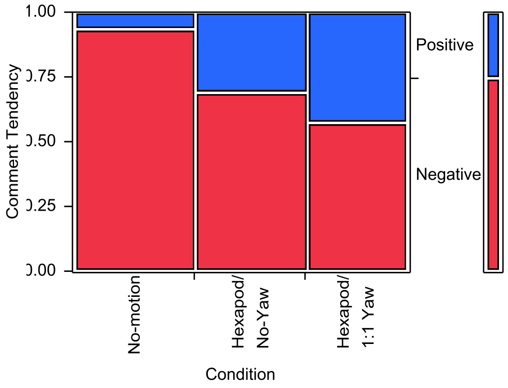

Fig. 6. Percentage of negative or positive comments received for condition.

5.3. Driver performance

Nine driver performance variables were examined, including mean lane center position difference (LCPD), standard deviation of LCPD, maximal LCPD, mean speed, minimal speed, mean brake position, standard deviation of brake position, maximal brake position, brake time, mean steering wheel angle, maximal steering wheel angle, and standard deviation of steering wheel position.

One participant had missing data on all dependent variables. Repeated measures ANOVAs were conducted on each of these variables. Here we only report analyses in the intersection segment. Analyses in the traffic circle segment has not been completed. Independent variables included intersection type (right vs. left turn) and motion condition.

First, the main effect of intersection type was significant on some of these measures. The maximal lane deviation and the mean lane deviation was larger for the left turn than the right turn, $F(1,53) = 64.89$, $p < .001$; $F(1,53) = 16.02$, $p < .001$, respectively.

The maximal, mean and standard deviation of steering wheel position is also larger for the right turn than the left turn, $F(1,53) = 291.82$, $p < .001$; $F(1,53) = 289.71$, $p < .001$; $F(1,53) = 206.11$, $p < .001$.

The mean brake position was larger for the right turn than the left turn, $F(1,53) = 4.04$, $p = .049$. The minimal and mean speed was larger for the left turn than the right turn, $F(1,53) = 20.16$, $p < .001$, $F(1,53) = 66.34$, $p < .001$ respectively.

The main effect of condition was significant on maximal brake position, $F(2,53) = 8.22$, $p = .001$ and marginally significant on the mean speed, $F(2,53) = 3.01$, $p = .06$. Simple effect analyses showed that participants brake harder in the No-motion condition compared to the two motion conditions, and there was no significant difference between the two motion conditions.

None of the interaction effects were significant. See Table 2 for the means of the variables that showed at least a marginal significant main effect of motion condition.

Table 2. Condition means of variables with marginally significant effect of motion.

Motion condition	**Mean speed (mph)**	**Maximal brake position (degrees)**
No-motion	11.91	3.23
Hexapod/ No-Yaw	11.86	2.76
Hexapod/ 1:1Yaw	11.25	2.81

6. Discussion

6.1. Driver performance

An effect of motion cueing was found on maximal brake position. Participants braked less in the two motion conditions compared to the No-motion condition, consistent with Siegler et. al. [Sie1]. Adding yaw to hexapod did not affect this measure. This is understandable because peak braking occurred prior to the turn and not during the turn where yaw cueing would be present. In addition, we found a trend of lower mean speed during turns in the hexapod with yaw condition than the other two conditions. This replicated the finding of Hogema [Hog1] that yaw cueing resulted in lower mean speed. Hogema concluded this was because drivers drove more cautiously in anticipation of the turn as a result of experiencing rotational motion of the vehicle. However, no effect of motion cueing was found on any other measure. It is possible that maximal braking behavior during turning maneuvers is the most sensitive measure in a short driving route. The effect of motion cueing during intersection maneuvering on other driver performance measures may require a higher numbers of participants.

6.2. Realism questionnaire

Although no statistical difference was present between motion cueing conditions, we found a trend of higher ratings on Car Acceleration and lower ratings on Controlling Speed for the two motion conditions compared to the No-motion condition. Motion cueing increased the realism of Car Acceleration, consistent with previous studies [Col1; Dam1]. Results on Controlling Speed, however, was in the opposite direction as predicted. A clue to this discrepancy is indicated in the verbatim responses associated with Controlling Speed. Many drivers indicated they were not satisfied with the coasting response of the vehicle and characteristics of the brake pedal response during braking. They felt the vehicle did not allow them to coast to a stop as in the real car, the braking response was too fast, the pedal displacement was too short, and the pedal forces too high.

After investigation it was discovered these dynamics were the result of an earlier study's automated braking system model which was active during this study. It is interesting that the motion conditions exaggerated the perception of this vehicle model characteristic as noted in the subjective ratings.

6.3. SSQ

We did not find statistically significant or even a trend of difference between motion conditions in SSQ scores. However, there was a trend of worse discomfort symptoms in the traffic circle segment than the intersection segment. In addition, we found a trend of less discomfort symptoms reported in later sessions than earlier sessions regardless of motion cueing conditions, indicating a positive practice effect of reducing simulator discomfort. However, with limited number of participants it was difficult to detect these effects or motion cueing effect statistically.

Further studies will be needed to reexamine these effects with a higher number~~s~~ of participants. Moreover, in this study several participants reported symptoms in the baseline questionnaire. These pre-drive symptoms made it difficult to infer whether the post-drive symptoms were indeed caused by simulator driving. These participants, therefore, were not included in the analyses. Future studies will excuse participants with baseline symptoms.

7. Conclusion

In this study, we replicated the findings of prior studies that motion cueing had a positive effect on driver performance. This result indicates that the configuration of the current GMRDS is effective in using motion cueing to improve driver performance.

For simulator sickness and realism, however, we did not find any statistical effect of motion cueing. Further studies with a larger number of participants, improved questionnaire tools, and adjusted methodology are needed to better evaluate functions of the simulator in reducing simulator sickness and increasing realism.

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