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Investigation of Haptic Feedback in the Driver Seat

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Abstract—**We explore the impact of tilting the driver's seat according to the relative distance and velocity to objects outside the car using a haptic feedback chair in a driving simulator. We found that drivers perform best when (1) the seat tilts according to relative distance (*vs.* velocity) to objects outside the car and (2) the seat tilts forward (*vs.* backward) when the driver gets closer to a car in front of them. We also found that when visually and cognitively distracted, drivers perform better using haptic feedback than without. Our results suggest that adding haptic feedback to the car seat may improve driving safety and enjoyment by enhancing the driving experience.**

I. Introduction

Future automobile sensor systems may include various proximity sensors to detect objects outside the car. We explore conveying this information to the driver through the driver's seat using haptic feedback to enhance a driver's awareness of the road and improve safety. While visual feedback of proximity may seem the most obvious choice, a driver's vision is already heavily loaded: drivers simultaneously watch the road, perform shoulder checks, monitor instruments—all while driving. Thus, if they are attending to one event, it is easy for drivers to miss other changes in the scene, such as cars coming from the side due to phenomena such as change blindness [1]. Audio feedback may also be used effectively for an alarm when an object gets too close; however, audio would not be as suitable for continuous analog feedback about proximity of objects, since such an approach would require a modulated, always-on audio signal that may be annoying. In contrast, a driver's haptic modality is not overloaded, and a haptic driver seat could convey continuous analog information by tilting the seat forwards, backwards and side-to-side. However, it is not clear what the most effective way to do this is.

As a starting point, in the study reported here, we investigate tilting the driver seat forwards and backwards to exaggerate the feeling of the car's movement relative to objects in front of the car. Tilting the car seat exerts active forces on the driver which is a particular form of haptic feedback, similar to experiencing a push from an external object. We wanted to explore whether drivers could make use of additional haptic information about their surroundings to exhibit better driving behaviours. We believe that if people have an enhanced awareness of the relative distance or velocity to objects in front of them, people may respond more quickly to dangerous situations. For example, in one scenario we investigate, we imagine a car slowing down in front of a driver who is distracted. The car seat tilts backward according to the distance between the cars, making it feel like the driver is accelerating forward. This feeling of acceleration may cause the driver to look forward to see what is happening and press on the brake. Without the added acceleration, the driver would not notice that the car has slowed down in front until he looks out the front window, which may be too late. Thus, the exaggerated acceleration could prevent an accident. Other scenarios using the same approach include providing proximity to objects behind and beside the car to enhance the sense of what is around the car without the need to look.

Figure 1: Apparatus for experiments: Kawada JoyChair R1 (right), LogiTech steering wheel and foot pedals that were attached to JoyChair (bottom), one monitor showing oval track, lead car and gauges, and other monitor showing distracter task (top, left).

To investigate the usefulness of our approach, we have created a driving simulation environment connected to a car seat mounted on a motion platform to run our experiments. We designed our experiments to explore the following:

- Does moving a car seat interfere with driving?
- Does moving a car seat based on proximity to other cars improve driver awareness?
- Should seat movement respond to relative velocity (i.e. there is a sensor that measures velocity) or distance to objects (i.e. there is a proximity sensor) outside the car?
- Does haptic feedback in the car seat improve driver performance?

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We ran two experiments varying the type of tilting as well as providing a distracter task that required the driver to have additional visual and cognitive load to simulate distracting driving situations such as adjusting a navigation system.

Our findings suggest that tilting the car seat can improve a driver's awareness of objects around the car as well as driver safety by reducing response times. Tilting the seat does not hinder, but rather aids driving performance and awareness of other cars, especially in the presence of a visual distracter task. Our findings did not point to a clear choice between conveying relative distance or relative velocity, but suggest that conveying relative distance may be more easily interpreted. Taken together, our results suggest that the haptic modality is a useful vehicle for providing drivers with enhanced awareness of their surroundings.

II. Related Work

Research to improve driver safety is an ongoing concern since drivers are faced with increasing numbers of information devices in the car cockpit (e.g. cell phones, navigation systems, complex audio systems, and even televisions). These additional distractions can seriously reduce driver safety since attention is divided. For example, McEvoy et al. [2] found a four-fold increase in the likelihood of crashing when people were on their hand-held cell phones while driving. This effect has also been corroborated by [3][4]. Thus, we are hoping to use haptic feedback to help provide information about what is going on around the car without disturbing visual or auditory attention.

Enriquez et al. [5] found that haptic feedback in the driver cockpit improves reaction times to alarms compared to visual or auditory feedback. Their results motivated us to consider applying haptic feedback to the car seat rather than the steering wheel. Enriquez's motivation stems from studies that show combining input modalities balances mental workload [6] where mental workload is the ratio of demand to allocated resources [7], and that people respond to touch with fast reflex motor response [8]. In their study, they explored the utility of pneumatically driven pockets to a mock steering wheel to provide haptic feedback of error conditions during a simulated driving task. They discovered that haptic feedback on the steering wheel significantly lowered reaction times and that modulation of the vibro-tactile feedback could provide extra information to help drivers identify the problem more quickly.

We consider the situation where cars come dangerously close to each other. Thus, Enriquez et al's result may apply to feedback through the car seat: drivers may react more quickly to haptic feedback when cars are too close. Our particular scenario is slightly different because we consider continuous feedback of information with the expectation that a driver will interpret what is "too close" according to the context of the environment. For example, it is reasonable to be thirty meters from a lead vehicle in slow city driving, but less appropriate on a freeway at high speed.

III. Experimental Evaluation of the Haptic Car Seat

We created a common driving simulation apparatus for the two main experiments we are reporting. In our experiments, a driver is asked to keep a safe distance in seconds behind a lead car (represented as a blue triangle) as shown in Figure 1. We next describe our driving simulator and the dependent variables, followed by the individual experiments with their own independent variables.

A. Apparatus and Driving Simulator

Our experimental setup, shown in Figure 1, consists of the following:

- a computer controlled motorized Kawada Joy Chair R1 with 3 degrees of freedom (roll, pitch and yaw);
- a LogicTech Formula Force GP steering wheel, accelerator foot pedal and brake pedal;
- a simulated driving environment and display, and
- a second display to present a distracter task.

The software uses position control of the chair through a National Instrument PCI-MIO DAQ providing low latency (< 10ms) control. In all our experiments, the driving simulation controller specifies a voltage proportional to the desired angle of the chair according to the experimental condition and location of the car in front. For our experiments we only tilt the chair forwards and backwards ±15 degrees (i.e. modifying only the pitch). In pilot studies, we confirmed that decoupling the pedals from the movement of the chair does not work well so we attached the foot pedals to the JoyChair via a metal platform, allowing the foot pedals to move *with* the chair.

We developed a driving simulation environment using C++. The main simulation loop keeps track of the location of all the objects in the environment, displays these graphically, and sends haptic control signals through the haptic controller. The physics model updates the positions of all the objects in the scene based on a simple Newtonian physics model. The input from the steering wheel and pedals are input to the physics model to control the driver's car while the lead car is controlled by the experimental conditions.

The highway driving simulation has an oval track with a few turns and stretches of straight-aways. In one experiment, subjects follow another lead car on the road whose speed is regulated to simulate traffic (occasional changes, such as on a moderately busy highway). The lead car is depicted by a blue triangle with two red brake lights that appear when the car is slowing down. We determine the amount of tilt based on the distance or velocity between the subject's car and the lead car, depending upon the experimental conditions.

We add an extra gauge to the dashboard in the lower right of the display to provide visual feedback of the variable controlling the haptic feedback during a given trial (i.e. the relative distance or relative velocity between the cars). The gauge reading corresponds to the tilt of the chair: when the gage is straight up, the chair is in its rest position with a linear mapping to the particular sensor value in either direction. The scaling factor is called the haptic-feedback *vs.* visual motion ratio (HFMR) and is varied in the experiments according to Table 1 to determine its influence.

Our distracter task consists of displaying a number of red or blue squares on a second monitor placed to the side of the road display. During the experiment, the driver presses one of two buttons on the steering wheel to select whether there are more red or blue squares in the scene. By adjusting the total number of squares we can make the task more difficult, requiring more visual attention and cognitive load. We used either 9 squares (easy condition) or 25 squares (hard condition). The distracter task is designed to elicit behaviour during typical distractions like changing a radio station or dialing a cellphone.

1) Performance Measures

In our car-following experiments, we measure driving performance using two measures:

1. **speed deviation:** the standard deviation in the absolute difference between the velocity of lead-car and the driver's car, and
2. **distance deviation:** the standard deviations in the distance between the two cars measured in seconds.

The first measure evaluates whether the driver is staying with the flow of traffic. If the speed difference gets large it means the driver is either accelerating or decelerating relative to the lead car. Conversely, if the difference is 0, the driver is moving with the flow of traffic. The deviation of this difference indicates whether the subject is having difficulty maintaining the same speed as the lead car accelerates and decelerates. The speed deviation is insensitive to the actual distance between the cars.

The second measure uses the deviation in the distance between the cars to evaluate driving performance. A typical safe distance between cars is about 2s, yet each driver has a different sense of a safe distance; thus, we use the standard deviation around the mean for each subject in our calculation. We also use seconds to measure distance to normalize for different speeds.

Driving errors such as crashing into walls or the lead-car were also recorded.

For our distracter task, we use the number of questions answered and the correct percentage to estimate visual and cognitive load.

The driving simulation models a simplified driving experience. We instruct subjects to drive carefully and follow the lead car keeping a safe distance. We do not provide auditory feedback, true acceleration, and risk aversion strategies to influence speed/accuracy tradeoffs such as penalizing for crashing. In these initial explorations, these effects are not critical; however our future studies will investigate the impact of these variables.

Sensor Type/ Feedback	**HFMR Eqn.**	**HFMR**	**Description**
Relative distance	Tilt = HFMR * 6°/s * ($dist_{rel}$–2s)	-1	As cars move closer, chair tilts backward.
		+1	As cars move closer, chair tilts forward.
Relative velocity	Tilt = HFMR * 6°/(m/s) * vel_{rel}	-1	As the driver accelerates toward the lead car, the chair tilts backward.
		+1	As the driver decelerates from the lead car, the chair tilts backward.

Table 1: The four different treatments we investigated for controlling the haptic feedback. When HFMR=0, we do not have any haptic feedback and subjects can use the dashboard gauges to see the reading of the sensor.

B. Experiment 1: Impact of Haptic Feedback on Driving Performance without Distraction

Experiment 1 was designed to compare the driving improvement from different sensor types for haptic feedback and determine which is most useful in highway situations. We tested whether it is better to provide haptic feedback based on simulated sensors for either the relative *distance* between cars or relative *velocity* between the cars. Thus, one of our independent variables is sensor type and the other is HFMR for distance and velocity feedback.

A treatment in the experiment consists of multiple trials of the lead car speeding up and slowing down with a given HFMR and sensor type. The driver is required to keep a safe distance between the lead driver and himself by adjusting the gas and brake pedals while keeping on the road. We had three values (-1, 0, +1) for HFMR in each of the two sensor conditions, running each combination six times in a random order.

Both the lead car and the subject's car would start each treatment at a red light. A trial within the treatment had the lead car accelerate (or decelerate) to a desired speed and maintain its velocity and the user would attempt to follow the car staying safely behind (approximately 2 seconds). The desired speed for the lead car would change every 30-45 seconds to between 30 and 100kph causing the driver to have to notice and react to the changes in the flow of traffic. In the case that the user hits a wall, both cars are reset to the middle of the road in a stopped position. Each treatment runs for about 5 minutes and ends when the user completes the last lap. There are approximately 10 trials for each treatment depending upon how quickly the subject drives.

The subject is required to complete three laps of the course without crashing before beginning the experiment to help reduce the effects of learning how to drive in the simulator properly.

The experimental procedure ran as follows:

1. **Training Phase**: Subject drives the course without the lead-car for 3 laps. This data is not used in our analysis.

2. **Sensor Treatment 1:** Choose one of two sensor feedback conditions randomly (velocity feedback or distance feedback). Run through the three treatments (HFMR=-1, 0, +1) in a random order.
3. **Sensor Treatment 2:** Perform treatments for second sensor type.

After each treatment the subject fills out the following five questions on a 5-point Likert scale (1=agree completely; 5=disagree completely):

- The chair influenced my driving
- I was able to drive the car comfortably
- I enjoyed driving the car
- the chair's movements helped my driving
- It was easy to drive the car.

After each set of treatments for a sensor feedback type, the subject answered three discussion questions:

- How did the movements of the chair influence your driving?
- In which trial where the movements most beneficial and why?
- What did you like or dislike about this set of trials?

At the end of the experiment the user answered three more discussion questions:

- What did you find different between the two sets of trials?
- What type of movement did you prefer and why?
- Do you have any comments about your experience or any suggestions to help us improve?

We ran 7 subjects (1 female, 6 male) from the student population at the University of British Columbia. Five of the subjects were between the ages of 20 and 29, one subject was under 20, and one subject was between 30 and 39.

1) Results

We removed one subject's data from the analysis as this subject drove an average of 6.2s behind the lead car—since the haptic feedback is provided for 4s behind the lead car or less, the chair provided maximum tilt for this user's entire trial.

The questionnaire data shows that subjects did not rank the trials very differently, but the driving data in Figure 2 shows that users drove better and safer with distance feedback with a distance-HFMR of –1.

Figure 2 shows that the main effect was when using distance feedback with distance-HFMR=-1. Distance feedback with a distance-HFMR= –1 had an average standard deviation of 0.57 while all other trials (velocity or distance) had values of 2.72 or greater. These were statistically significant differences with $p<0.05$ except for distance-HFMR=1 which has $p<0.1$. The differences in the velocity measures for all conditions were negligible and not significant. One interesting finding is that when there is no haptic feedback (HFMR=0 for either distance or velocity sensors) we find

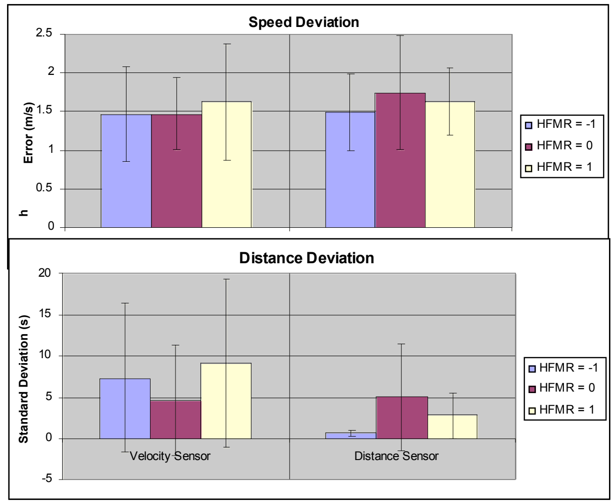

Figure 2: Standard deviation of distance in seconds and difference in speed in m/s. A lower value represents better ability at following the flow of traffic safely.

there is a discrepancy between the driver's performance for speed deviation (1.47m/s with velocity sensor vs 1.75m/s with distance sensor). The only difference between the two conditions is the different dashboard gauge showing velocity distance versus distance to the lead car. The performance difference was not significant distance deviation (4.58s vs 5.03s), though, suggesting drivers do not use the distance gauge to maintain position but find the velocity gauge useful for controlling relative speed.

The average amount of errors made in each treatment is much less for distance feedback over velocity feedback in general. No subjects made any errors for the distance feedback with a HFMR of –1 and only 2 errors were made in total when the HFMR was 1. The most common type of error was hitting the lead car.

From the questionnaire, subjects ranked velocity feedback as having more influence on their driving. Distance feedback with a HFMR of –1 was ranked lowest (3.3) on whether the chair's movement helped with driving while all others are ranked very closely (4.0). Velocity with a HFVF of 1 ranked highly on ease of driving (4.6).

2) Discussion

Driving performance was best with distance sensor and a distance-HFMR=-1. The worst performance was with velocity sensor and a velocity-HFMR=1. It is interesting to note that even without haptic feedback (HFMR=0) and only visual information from the dashboard gauge, relative velocity provided better feedback than distance for driving performance. We also note that from the questionnaire data, subjects generally ranked the distance feedback with HFMR=1 best. This seems to contradict the results from the measured performance data even when subject who had difficulty driving in this condition were removed from the analysis. This contradiction warrants further study as it suggests that people's sense of their performance using haptic feedback is different than their actual performance. In general though, the questionnaire results only show small differences.

Since the data showed that distance based feedback with a HFMR of –1 was most beneficial in improving the driving safety and performance, we used this type of feedback for Experiment 2.

C. Experiment 2: Impact of Haptic Feedback on Driving Performance with Distraction

Experiment 2 was designed to test whether there are significant driving performance increases using haptic feedback while the driver is distracted mentally and visually (i.e. under increased visual and cognitive load). We use the distracter task to represent activities such as tuning the radio, looking for parking spots, or dialing on a cellphone, and as described in our apparatus section, vary the difficulty of the task to simulate various levels of cognitive loading. Our hypothesis is that drivers would be able to use the haptic feedback about the traffic in front of them to increase their vigilance without needing to attend to the front view out of the car as much.

Two difficulty levels for the distracter were used (easy and hard) and each was tested with and without haptic feedback. We ran six treatments equally divided between HFMR=0 and -1 as described below. Each trial within a treatment is the same as for Experiment 1, thus, for a given treatment we have about 10 trials depending upon how long a subject takes to go around the track. We ran 10 subjects (2 female, 8 males) between the ages of 20 and 60 from the University of British Columbia.

The procedure for Experiment 2 is as follows:

1. Training Phase A: complete 3 laps without crashing without haptic-feedback or a lead-car. There was no training phase for the distracter task.
2. No distracter, HFMR=0 for 5 minutes of driving
3. No distracter with HFMR=-1 for 5 minute of driving
4. four 5 minute treatments randomly ordered from the following table of conditions:
    1. With Haptic Feedback (HFMR=-1), 9 block distracter (Easy)
    2. With Haptic Feedback (HFMR=-1), 25 block distracter (Hard)
    3. Without Haptic Feedback (HFMR=0), 9 block distracter (Easy)
    4. Without Haptic Feedback (HFMR=0), 25 block distracter (Hard)

After each treatment the user answered the same questions as in Experiment 1 with one additional question addressing the distracter task: "I was able answer the questions without hindering my driving."

At the end of the experiment the user answered six discussion questions:

- How did the movement of the chair influence my driving?
- Compare driving with and without the chair moving.
- What are your thoughts on the movement of the chair?
- Were the questions too easy or too difficult? Why?
- Were the chair's movements able to help you answer more questions while still driving safely? Why?
- Do you have any comments about your experience or any suggestions to help us improve?

As in Experiment 1, each treatment was run with the subject attempting to follow the lead-car safely (i.e. around 2 seconds behind) while the flow of traffic varied. Data from the first three steps were not used in the analysis as they were to mitigate learning effects.

1) Results

Subjects' speed deviation was lowest with haptic feedback whether they had a hard distracter (2.5m/s with haptics vs. 4.0m/s without) or easy distracter (3.2m/s with haptics vs. 4.7m/s without). Their distance deviation was also lowest with haptic feedback (hard: 8.5s with haptics vs. 10.9s without, easy: 19.7s with haptics vs 21.2s without). While none of these differences meet a significance criterium, they are consist in their trend and thus suggest further experiments to determine significance levels.

There was no significant difference in the percentage of correct answers for the following conditions:

- Easy Distracter
    - With haptics: 91% correct, 120.7 out of 133.1 versus
    - Without haptics: 94% correct, 112.8 out of 120.4
- Hard Distracter
    - With haptics: 79% correct, 30.2 out of 38.2 versus
    - Without haptics: 83% correct, 16.8 out of 20.4

Subjects were able to complete almost twice as many questions with feedback for the hard distracter and still perform at the same accuracy.

From the questionnaire, subjects found it easier to drive with haptic feedback. This is much more noticeable when they have the distracter task. The enjoyment of driving the car stayed about the same through all trials but does have a slight trend of being more enjoyable with feedback.

The average number of serious driving mistakes for each treatment was grouped into three types of errors: hitting the wall, stopping, and hitting the lead car. Subjects made fewer mistakes with haptic feedback than without for both types of distracters (hard: 3.2 mistakes with haptics vs 4.0 mistakes without, easy: 3.2 mistakes with haptics vs 7.8 mistakes without). Subjects did hit the wall more often with haptic feedback though. There is only a small improvement for the hard distracter but a very large improvement for the easy one when using haptics compared to without.

2) Discussion

Results from Experiment 2 show that subjects drove more safely and responded to the distracter task better with haptic feedback than without. The subject feedback supports this trend as they felt it was much easier to drive with haptic feedback. Some users commented that after getting used to driving with haptic feedback they would rely on it completely to warn them even on trials where there was no haptic feedback.

With haptic feedback, participants made fewer "critical mistakes" in every category except crashing into walls. We conjecture that this is because there is no warning for turns and the subject is busy completing the distracter task and regulating their distance from the lead car by only using the haptic feedback. Future plans include adding haptic feedback warnings for objects to either side of the car as well as including force feedback about the road conditions such a curves. Also, force feedback about curves would normally be available in a real car due to the change in inertial momentum when turning and banking of curves.

The number of questions correctly answered for the easy distracter showed no significant difference when either haptic feedback was present or not, however, the quality of driving improved with haptic feedback. This is because users found the easy distracter fun and engaging so tried to answer as many questions as they could as if it was a game, and in either case and they let their driving get sloppy. However, with haptic feedback they were still able to maintain control of the car better and notice when the lead car changed velocity. This suggests that they were able to integrate the haptic feedback information effectively as part of the information sources needed to perform the complex set of tasks in the experiment (i.e. driving, watching the road, performing the distracter).

An interesting counterintuitive note is that, in general, subjects drove better on the trials with the harder distracter than with the easy one. As mentioned above, discussions with subjects suggest this may have occurred because participants got caught up in the easy distracter task, while the hard distracter requires more time to answer. Consequently, subjects tended to look at the road more while working on the difficult distracter task. Ironically, this result suggests that the easy distracter was actually more distracting. Making the questions timed and only appear at a set rate could rectify this. For the purposes of our experiment, we only required different levels of distraction to determine the impact of haptic feedback on driving performance, thus, the current method is effective.

Summary and Future Work

Our experiments are a starting point to investigate haptic feedback from the car seat. We are planning to enhance the experimental framework to overcome some of the scope limitations of our results. Ultimately, we will need to place a computer controlled tilting chair and associated sensors in a real car to fully understand the interactions between the two. We plan to enhance our methodology by:

- replicating the external forces made from the car accelerating;
- enhance our physics model to better simulate the driving experience including adding road properties and other car behaviours;
- increase the field-of-view for the road display to provide a stronger sense of immersion;
- better incorporate crashing behaviour: increase the impact of crashes so that drivers feel more like real driving than a video game;
- explore the long term effects of haptic feedback including determining whether there are negative transfer effects to vehicles without or different feedback. and
- explore other driving environments such as urban settings.

In our experiments, we used the time between cars at their current speed until collision as our distance metric. However, in our next set of experiments we would also include the perceived time to collision (TTC) to see if there is a speed effect on driver's sense of danger with or without haptic feedback. Further, our haptic feedback chair does not provide any translational forces. However, the sense of acceleration is greatly enhanced with translation and rotation; thus, we would like to run our experiments using a chair on a Stewart platform as well.

In summary, our work makes three contributions: first, we have designed and implemented a system providing in-seat haptic feedback about current driving conditions; second, we have contributed a method to evaluating the effectiveness of such a device in driving conditions, both under easy and hard distraction; finally, we have demonstrated that haptic feedback in a seat is useful in promoting better driving behaviours under both heavy and light workload conditions. Further, our subjects reported enjoyed the feeling of the chair tilting. Taken together, these promising results encourage us to continue investigating the role that haptic feedback to the driver seat may have in increasing driver safety and enjoyment of driving in actual cars.

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