ABSTRACT

THE EFFECTS OF A FORCE FEEDBACK ENABLED SECONDARY TASK ON DRIVER PERFORMANCE ON A SIMULATED LANE CHANGE TASK.

By

Martin T. Koltz

May 2015

Distracted driving can be dangerous and new technology is being implemented into vehicles that will likely increase the amount of distraction present. New input device technology has made it possible to use force feedback to aid in task completion which may help reduce the cognitive load of secondary tasks. In the present study, participants performed a simulated lane change task while simultaneously completing a target selection task. Participants used the Novint Falcon input device which is capable of applying guiding force feedback. Two levels of two different force feedback models were used on the secondary task as well as a no force feedback baseline. Results indicated that when force feedback was enabled on the secondary task and at its highest magnitude, driving performance was better than when no force feedback was enabled. Additionally, secondary task performance was consistent with previous single-task force feedback research.

THE EFFECTS OF A FORCE FEEDBACK ENABLED SECONDARY TASK ON DRIVER PERFORMANCE ON A SIMULATED LANE CHANGE TASK.

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INTRODUCTION

Multitasking on its own does not pose any inherent risk. However, it does become problematic when errors in a primary task due to distraction caused by a secondary task have the potential to cause harm to the operator or others. This is especially true in the case where the primary task is a complex control task such as driving a car. Despite the dangers of multitasking in this type of environment, the number of drivers performing non-essential secondary tasks is increasing (Pickrell & Ye, 2013). Further, as technology becomes more powerful and at the same time more portable, drivers are increasingly encouraged to multitask. For instance, General Motors announced that more than 30 of its 2015 model year vehicles would be equipped with 4G LTE wireless Internet connections (General Motors, 2013). In-vehicle Internet access has the potential to create a wide range of new distractions. It is therefore increasingly important to both understand and identify the sources of distracted driving as well as develop methods for mitigating their detrimental effects on driving performance.

Distracted Driving

Reagan, Lee, and Young (2009) identified 14 unique definitions of distraction that have appeared over the last 20 years of driving research. Based on these definitions, Reagan et al. concluded that distraction should be defined as "… a diversion of attention away from activities critical for safe driving towards a competing activity" (Reagan et al., 2009, p. 34). Despite the dangers associated with distracted driving, it is increasingly common (Pickrell & Ye, 2013; Redelmeier & Tibshirani, 1997). In fact, in-vehicle sources of distraction not directly related to driving account for up to 62% of accidents associated with driver distraction (Reagan et al., 2009). Further, since these types of distractions are not directly related to driving, they can be more easily modified or eliminated.

There are many sources of in-vehicle distraction including audio video entertainment systems, GPS navigation systems, and information and communication systems (Reagan et al., 2009). These systems can be portable or fixed within the vehicle. Listening to audio from these devices does not appear to have a significant impact on driving performance; however, manipulating these devices significantly reduces driving performance by increasing response time to hazards, reducing the amount of time looking at the road, and increasing the amount of time spent looking inside the vehicle (Reagan et al., 2009).

Salvucci, Markley, Zuber, and Duncan (2007) investigated the impact of manipulating a portable entertainment device on driving performance in a fixed base simulator. Participants were asked to follow the centerline of their lane and follow a lead vehicle that maintained a constant speed at a reasonable distance. At the same time, participants were asked to find and play various types of media using an Apple iPod. The researchers measured the root mean square lane deviation and average vehicle speed during the time participants were listening or watching the content and while they were manipulating the device. Results showed that there was no significant difference in the driving performance measures between the baseline condition and any of passive media consumption tasks, but there was a significant effect due to manipulating the device. Root mean square lane deviation was significantly higher when participants were using the device to search for media. Interestingly, average speed was significantly lower while participants were manipulating the device. The researchers concluded that participants were aware they were distracted and adjusted their speed to increase following distance accordingly. Further, it was concluded that the main source of the distraction caused by manipulating the device was due to the visual processing required by the interaction mode used by the iPod. The iPod uses a thumb wheel to scroll through lists of media. This type of interaction requires a significant amount of visual processing to monitor the item that is currently selected and it provides no means of feedback other than vision to determine how far the user has scrolled.

Other input and output modalities for secondary tasks have been studied and results indicate that secondary tasks that require visual processing and manual output produce the greatest interference with the primary task of driving. For example, Vollrath and Totzke (1999) had participants drive in a simulator on both straight and curving roads while performing secondary tasks that required various input and output modalities. Three types of secondary tasks were used. The first was a manual task in which a name was presented on a computer screen and the participant was required to select the address associated with that name from an address list using a joystick. The second and third tasks were visual information processing and auditory information processing. Simple sentences were presented visually or over speakers and participants needed to say “yes” or “no” depending on whether or not the sentence was meaningful. Results showed that of the three tasks tested, the manual secondary task had the greatest negative impact on driving performance. This was followed by the visual information processing task, which negatively affected performance only on the curved portion of the drive.

A limitation of the studies conducted by Salvucci et al. (2007) and Vollrath and Totzke (1999) is that they both investigated the effects of various distractions using a driving simulator. Simulator studies have the advantage of being safe and allow for more rigorous experimental control, however, it can be difficult to draw real world conclusions from these types of studies due to limited fidelity of the simulator.

Hancock, Lesch, and Simmons (2003) investigated the effects of a secondary task that required both visual information processing and manual output on a test track in a real car. Participants drove two blocks of 24 laps around a test track that had a simulated intersection. Four conditions were tested throughout the 24 laps. On four trials, as the vehicle approached the intersection, a traffic light turned red and participants were required to stop as quickly as possible. On four trials a tone would sound in the vehicle and a digit would appear on a simulated cell phone presented on a touch screen. Participants were asked to indicate by pressing a button on the touch screen if the digit was the same as the first digit of a number they had memorized at the beginning of the trial. On four trials, both the digit memorization task and the stopping task were presented together. Finally, on the remaining 12 trials, no distractor or stopping task was presented. Researchers measured mean braking reaction time, mean stopping time and distance, and stopping accuracy. Stopping accuracy was measured by the percentage of times participants stopped the vehicle when the signal instructed them to do so. Results indicated that the digit task, which required visual processing and a manual response, significantly decreased driving performance measured by increased reaction times to the traffic signal and reduced stopping accuracy.

It is clear that secondary tasks utilizing a visual stimulus and a manual response impose the greatest interference on driving as driving is primarily a visual spatial task. However, the majority of the cognitive interference may be due to processing the visual stimuli rather than simply detecting them (e.g., Chong et al., 2014; Martens & Van Winsum, 2000). Therefore, technology that attempts to reduce perceptual load, heads up displays for instance, may not be effective due to the fact that they may do nothing to reduce the amount of visual processing the driver must perform. Thus, finding ways to reduce the cognitive impacts of secondary tasks is necessary due to the fact that the amount to which the two tasks require the same cognitive resources represents a powerful predictor of dual task performance (Wickens, 1981).

Multiple Resource Theory

All cognitive tasks require a certain amount of effort to be put forth in order to achieve a desired level of performance. Navon and Gopher (1979) introduced the concept of resources to describe the amount of cognitive effort devoted to task performance. Using this analogy, cognitive resources are assumed to be finite. Therefore, they must be appropriately allocated in order to achieve a desired level of performance (Navon & Gopher, 1979). The assumption that these resources are of a finite quantity does not necessarily mean that each individual has the same resource capacity or will employ the same strategies in allocating them. In fact, the supply of resources may not be fixed from one moment to the next. This notion of variable quantity of cognitive resources and varying allocation strategies based on the specific task is referred to as a subject-task parameter. On any given day for any given task, an individual can achieve a certain level of performance. However, the same individual may not be able to achieve that same level of performance on the same task at another time. Subject-task parameters also consider the demands that a task places on the individual and assumes that this is not constant from one person to the next. In other words, a task may impose a high level of demand on one operator but a low level of demand on another.

There are two types of limited capacity theories; the undifferentiated resource model and the multiple resource model. The undifferentiated limited capacity model of time-sharing does not assume any bottlenecks due to serial processing or perception. Rather, it assumes that there is a single pool from which the required cognitive resources can be drawn to produce the desired level of task performance (Wickens, 1981). As the requirements of the task or tasks increase and resources become depleted, performance may decline.

Multiple resource theory attempts to explain the results of myriad time-sharing studies that cannot be explained by the undifferentiated capacity theories (e.g., Wickens, 1981). Three main challenges to the undifferentiated capacity theories have been identified: perfect time-sharing, difficulty insensitivity, and structural alteration.

Perfect time-sharing refers to the phenomenon in which two tasks can be performed concurrently at a level of performance that is no different than when the tasks are performed in isolation. For example, Allport, Antonis, and Reynolds (1972) had participants perform a speech-shadowing task at the same time they performed complex visual tasks such as site reading music. Results showed that performance on both the shadowing task and the visual task when performed together was no worse than when those tasks were performed separately. If there were a single pool from which cognitive resources are drawn, performance on at least one of these tasks should have been observed.

Another result that can occur in time-sharing studies that cannot be explained by the undifferentiated resource model is difficulty insensitivity (e.g., Proctor, 2004). Difficulty insensitivity is when increasing the difficulty of one of the two tasks being performed does not lead to degraded performance to the other task. Again, the undifferentiated resource theory would not predict these results. Tsang and Vidulich (1987) demonstrated the difficulty insensitivity phenomenon by having participants complete two tracking tasks simultaneously. The primary tracking task used a visual indicator to represent the current error which participants corrected using their right hand on a joystick. The secondary task was also a tracking task but two different modalities were used to present the current error. One of the modalities was a visual stimulus similar to the primary task and the other used an auditory stimulus that displayed the error using two speakers located one on either side of the participant. Participants used their left hands on a second joystick to make corrections on the secondary tracking task. Single task performance showed significantly higher average error when the secondary task used the auditory modality versus the visual modality; researchers concluded that the task using the auditory stimulus was the more difficult task. Thus, it was expected that primary task performance would be lowest when the secondary task modality was audition. However, results showed that there was no interaction between primary task performance and secondary task modality (Tsang & Vidulich, 1987). In other words, the decrease in performance due to the secondary task was the same regardless of which modality the secondary task used. Again, these results would not be predicted in the case that a single pool of resources is being employed for both primary and secondary tasks.

Another problem for undifferentiated capacity models is known as structural alteration (Proctor, 2004). Structural alteration refers to the situation in which the structure of the secondary task, input modality for instance, is changed but the difficulty of the task is held constant. The undifferentiated capacity model would predict that performance on both the primary and secondary tasks would remain constant due to the fact that the total volume of required undifferentiated resources should not change. However, Mcleod (1977) had participants perform a continuous tracking task concurrently with a choice identification task. Participants were divided into two groups, one responded to the choice task verbally and the other made manual responses with the hand not used for the tracking task. In all respects, aside from output modality, the two secondary tasks were the same. Results showed that when the response modality for the secondary task was a motor response, performance on the primary task suffered to a greater extent than when the secondary task required verbal output. Thus, it was concluded that two tasks that required motor control for output interfered with each other more than a motor response combined with a vocal response (Mcleod, 1977).

In order to explain these problems with the undifferentiated capacity model, Wickens (1981) concluded that a system must exist in which there are specific pools of resources that support different processes and do not overlap. In this way, it is possible for two tasks to be time shared perfectly as long as they do not require the use of the same pool of resources. Difficulty insensitivity is also predicted by the multiple resource theory. As long as the two tasks do not require a shared pool of resources, changes in difficulty in one task should have no effect on the other. Changing the structure of one task such that it overlaps another task means that a shared pool of resources is now required for both tasks when before separate pools could be utilized.

The multiple resource model states that cognitive resources are separated along 3+1 dimensions (Wickens, 1981). Those dimensions are the information processing stage, the processing code, and the input modality. The +1 dimension refers to a division within the visual input modality, foveal versus ambient. Specific divisions within each dimension have been established (See Figure 1).

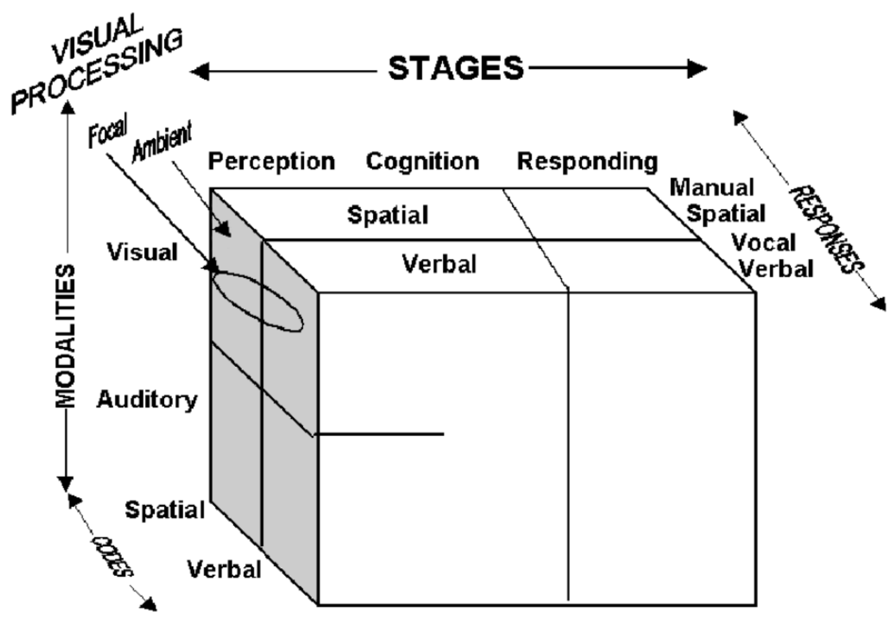

FIGURE 1. Illustration of the 3+1 dimension multiple resource model.

The information-processing dimension consists of the perception stage, the cognition stage, and the response stage. Modality is separated into audition and vision and the processing code is divided into spatial processing and verbal processing (Wickens, 1981). Every task includes some component of each dimension and is predicted to interfere with another task to the extent that the two share those components.

The predictions of the multiple resource theory have been studied at length and verified based on neurological evidence (e.g., Just et al., 2001; Previc, 1998) and computational models (e.g., Wickens, 2002); however, these studies considered vision and audition as the only modalities that can be utilized during the perception stage of information processing. New input device technologies using force feedback make it possible to explore a third modality that can be utilized during the perceptual stage of information processing, touch. In this context, touch encompasses many senses, such as the tactile sense and kinesthetic force feedback sense.

Force Feedback

Force feedback refers to the ability of an input device to apply physical forces on the operator to provide information or guidance. These force models follow specific rules and can be used to assist the operator in completing a task or deter the operator from making a mistake. Originally, the technology was studied as a way to enhance teleoperations through haptic displays for virtual or remote environments (Griffiths & Gillespie, 2005). These types of haptic displays are known as virtual fixtures and have been shown to lead to performance improvements in tasks ranging from simple remote peg-in-hole tasks (e.g., Rosenberg, 1993) to minimally invasive robotic surgery (e.g., Park, Howe, & Torchiana, 2001). These studies used virtual fixtures to create physical barriers within the virtual world in order to keep operators out of areas in that environment that may be hazardous. Typically, virtual fixtures are fixed relative to the reference frame of the virtual environment. However, force feedback can also be used to direct operators towards a desired target or along a specific paths using dynamic force models based on the location of the controller relative to a target within the environment (Abbot, Marayong, & Okamura, 2007). This type of feedback is known as a guidance virtual fixture and has proven to be useful for improving performance on many human-computer-interaction tasks.

Dennerlein and Yang (2001) utilized an attractive force feedback model that actively pulled a user’s mouse towards a specified target. Targets appeared along a vertical or horizontal line and participants were asked to move their cursor to the target and select it. After each selection, a new target would appear and the next trial would begin. When the attractive force was active, movement times were found to be approximately 25% faster than when the force was disabled. An additional benefit of the attractive force was that it also reduced the perceived level of discomfort participants reported after completing 540 trials (Dennerlein & Yang, 2001).

The target selection task used by Dennerlein and Yang (2001) is typical of force feedback studies that often utilize Fitts’s law to make objective comparisons between the performance of different input devices. Fitts’s (1954) law can be used to estimate the movement time for a target selection task based on task variables such as target width and distance as well as device performance constants. In addition to predicting movement times Fitts’s law can also be used to compare the effectiveness of different input methods by controlling the index of difficulty and gathering movement time data. The slope and intercept of the line that best fits the movement time data represents the specific performance of the input device. These device parameters can then be used to compare the performance of one device to another.

Overall movement time provides a top level view of device performance however in order to understand the effects of attractive force feedback displays in more detail, Akamatsu and MacKenzie (1996) divided the target selection task into its component parts. They defined the approach phase as the movement that takes place outside of the boundaries of the target. The selection phase was defined as the movement that takes place within the boundary of the target up until the target is selected. Participants were instructed to move their cursor from a starting location in the bottom left corner of the display to a target area in the top right corner of the display. During the time the cursor was within the boundary of the target area, either no feedback, tactile feedback, a friction force, or a combination of both the tactile feedback and friction force was provided. No difference in approach time was found for any of the feedback mechanisms. However, both the tactile alone and the force feedback alone condition resulted in significantly lower selection times. Akamatsu and MacKenzie concluded that the additional feedback reduced the perceptual load on the visual system by providing an additional means of detecting when the cursor had entered the target. In this way, the tactile sense was being used as a perceptual modality similar to vision or audition. More recently, Rorie et al. (2013) used a non-conventional input device called the Novint Falcon to investigate the effects of a combination of force models at varying levels. An attractive force based on Newton's gravitational equation was utilized to direct participants towards the target. Once inside the boundaries, a spring force based on a standard spring equation helped to keep the cursor centered within the target. Results showed a significant decrease in overall movement and approach time as the intensity of the gravitational force was increased. There was also a significant reduction in the selection time due to increases in spring force (Rorie et al., 2013). Further, when compared to performance using a traditional no-force-enabled mouse, the Novint Falcon with force feedback performed as well if not better (Rorie et al., 2013). This was a surprising performance gain considering that in an earlier study using the same task, the Novint Falcon with no force feedback was found to be nearly 50% slower than a standard computer mouse (Rorie et al., 2012).

Studies like Rorie et al. (2012, 2013) and Koltz et al. (2014) highlight the performance benefits of force feedback for human computer interaction target selection tasks. These studies show significant improvements in target selection time, however the absolute magnitude of the performance gain tends to be on the order of only a few hundred milliseconds. When aggregated over a few hundred or a few thousand target selection tasks, this difference begins to add up; however, in real world applications, target selection may comprise only a fraction of the overall task. Researchers often conclude that reductions to time in target measurements are due to the tactile modality being a more efficient input channel on which to make physical response selections such as clicking the mouse. If this is the case, it would be more applicable to gain an understanding of how these freed up visual resource could be allocated to improve performance on another task such as driving.

Tactile Feedback in Driving

Tactile feedback has proven to be effective at improving driving performance when used as simple warning system. Scott and Gray (2008) investigated the effects of rear end collision warning systems using different modalities in a fixed based driving simulator and highlighted the effectiveness of the tactile modality in bringing attention to highly task relevant stimuli (in this case an imminent rear end collision). Participants were instructed to follow 2 seconds behind a lead car in a driving simulation. The lead car randomly sped up, slowed down, and stopped in order to induce possible rear end collisions. In some cases a warning system alerted drivers either 3 or 5 seconds before an accident would occur through either an audible tone, a tactile alert, or a visual indicator. Reaction time to brake and the number of collisions were recorded as dependent variables. Results showed that any warning system was better than none and that the tactile warning system was better than the audible system and the visual system in terms of reaction time. However, the warning type had no effect on the number of collisions that occurred. This study shows the effectiveness of the tactile modality even though the tactile display used by Scott and Gray could only show Boolean type information. That is, when it was on, it indicated a rear end collision was imminent and when it was off no information was provided. However, tactile displays that present more than a single bit of information are also possible and have proven to be more effective at reducing workload than visual displays presenting the same information (Van Erp & Van Veen, 2004).

Van Erp and Van Veen (2004) embedded tactors into the left and right side of the lower portion of the seat in a driving simulator. The tactors were used as a navigation display. As the participant neared the next turn the vibration pulsed on and off more rapidly and the side of the seat that was activated indicated the direction of the turn. Participants drove through a simulated route using the tactile display, a visual display, or a combination of the two. Results showed that subjective workload ratings were lowest with the tactile display and reaction times to navigation messages were significantly lower when the visual and tactile displays were combined. It was also shown that when the navigation contained the tactile display either on its own or combined with the visual display, workload load as measured with a peripheral detection task was insensitive to changes in task difficulty. These results indicate that the tactile modality can be used to provide information of varying density with little interference to tasks that rely on the visual modality. What these displays lack is the ability for the user to interact in any way. Force feedback enabled displays can provide information through the tactile modality while still allowing the user to make inputs. This makes force feedback especially interesting in the context of distracted driving.

Griffiths and Gillespie (2005) investigated the effects of a force-enabled steering wheel that helped guide drivers in a simulator towards the center of the lane. Their goal was to understand the impact of what they called shared control on driver performance, visual demand, and workload. The primary task was to drive a simulated road course that had numerous turns and obstacles with the aid of an automated steering system that gently guided the driver back to the center of the lane. The automation was not programed to avoid the obstacles meaning the driver was responsible for this part of the task. Results of the baseline experiment showed that when the feedback was active average driver error as measured by the mean deviation from the center of the roadway was significantly lower. However, drivers hit a significantly higher percentage of the obstacles with the feedback than without due to the fact that the feedback was set to help maintain the centerline, which is where the obstacles were placed.

To investigate whether or not the force feedback reduced the visual demand of the driving task, a second experiment was conducted in which the driving task was identical to the baseline experiment but the display was blanked. Participants had to activate the visual display by pressing a key on a keyboard. After 1 second, the display was again blanked. The visual demand of the task was then inferred from the percentage of the time the display was active. Results showed that the force feedback both improved driving performance and reduced visual demand. When the feedback was active, participant requested the visual display for a significantly lower proportion of the time than when the force feedback was turned off. Finally, a dual task paradigm was used as means of understanding how the haptic feedback influenced workload. Again the driving task was the same, however a secondary tone localization task was added in which participants responded with keyboard inputs based on which side of them an auditory tone was presented. Because the driving task and localization task both required spatial processing and manual responses, interference between them was expected to be high. Thus, reductions in demand due to the automated feedback were expected to improve performance on the localization task. There was no accuracy improvement in the localization task due to the automation. However, localization response reaction times were significantly lower when the automation was on suggesting that the automation did allow more resources to be devoted to the secondary task.

When comparing the baseline, no automation conditions of the driving task performed in isolation versus concurrently with the tone localization task, Griffiths and Gillespie (2005) found that the secondary task reduced primary task performance by as much as 18%. However, when the force feedback was active driving performance only suffered a 6% reduction in primary task performance due to the secondary task showing the effectiveness of the force feedback model that was utilized.

Griffiths and Gillespie (2005) chose a secondary task that would interfere with the primary task in both processing and response, however the input modality did not overlap. The primary task used visual and tactile inputs and the secondary task used auditory inputs. While there are some sound localization tasks in driving such as detecting where the sound of another vehicle's horn came from, the conclusions that can be drawn for real world applications are limited since sound localization tasks are not common in this context. Furthermore, because of the purpose of their study Griffiths and Gillespie chose to utilize force feedback on the primary task rather than the secondary task.

Typically, secondary tasks in the real world are less difficult than the primary tasks. In a driving situation for example, changing the radio station is a simple target selection task while maintaining the centerline of the road while avoiding obstacles and watching the vehicle's speed represents a significantly more complex task. Adding force feedback as an aid to maintaining the roads centerline only aids in a small proportion of the overall primary task. However, adding force feedback to the task of changing the radio station may aid in a much greater proportion of the overall task. Thus, as a way of reducing overall workload and increasing driving performance it may be more beneficial to find ways to reduce the load due to relatively simple secondary tasks by utilizing force feedback.

Purpose

Distracted driving is both dangerous and ubiquitous. New technologies are being introduced that increase the connectivity of our vehicles and encourage drivers to engage in tasks not related to safe driving. At the same time, new requirements for in vehicle electronic systems are being developed to reduce the negative impact of these types of devices on a driver's attention. Much of the research involving distracted driving has focused on the impacts of various types of secondary tasks. Results of these studies show that visual manual tasks impose the greatest interference on driving. The cognitive tunneling that occurs in the visual system is not caused by a reduction in the ability to detect stimuli; rather, it is caused by the processing system for the visual channel reaching its maximum capacity. Therefore technology intended to reduce visual demand by placing items closer to the central field of view (e.g., heads up displays) will not necessarily represent an effective means of reducing distraction, as they may do nothing to reduce the demand on visual processing.

Data from non-driving studies involving target selection tasks indicate that force feedback displays offer an effective means of offloading visual processing demands to the kinesthetic modality. In the driving context, force feedback when applied to the primary task has been shown to improve driving performance and reduce visual demand while tactile displays significantly reduce reaction times to collision warning systems and aid in vehicle navigation. However, little has been done to investigate more complex force feedback displays as a method for reducing the visual processing demands of secondary tasks. The purpose of the present study was to investigate performance differences on a standardized lane change task when a secondary task utilizes various levels of force feedback versus when no force feedback is used on the secondary task. It was hypothesized that performance on the primary task would be greater when force feedback was active on the secondary task than when no force feedback was active on the secondary task.

CHAPTER 2

METHODS

Participants

Twelve participants (6 women and 6 men) ranging in age from 31 to 22 years old (*M* = 24.58 years old) were recruited from the Psychology Department at California State University, Long Beach. Each participant had a valid driver's license and had more than four years of driving experience (*M* = 8.58 years of driving experience). Participants drove 125 miles per week on average and the maximum weekly mileage reported was 300 miles and the minimum weekly mileage reported was 20 miles. All participants were right handed and had normal or corrected-to-normal vision. Eight of the 12 participants indicated that they regularly played video games (*M* = 6.75 hours per week). Of those eight, four indicated that they played driving videos games (*M* = .69 hours per week).

TABLE 1. Demographic Summary

	Mean	*SD*	Min/Max
Age (years)	24.5	2.6	22/31
Driving Experience (years)	8.58	3.3	4/15
Weekly Mileage (miles)	125	104.9	20/300

.

Materials and Apparatus

Testing was conducted in a sound attenuating room where a large projector screen was used to display the primary task. The primary task was the standardized lane change task specified by ISO 26022. The lane change task required participants to drive a simulated vehicle using a Logitech G-27 racing steering wheel and pedal set down a three-kilometer long, three-lane track.

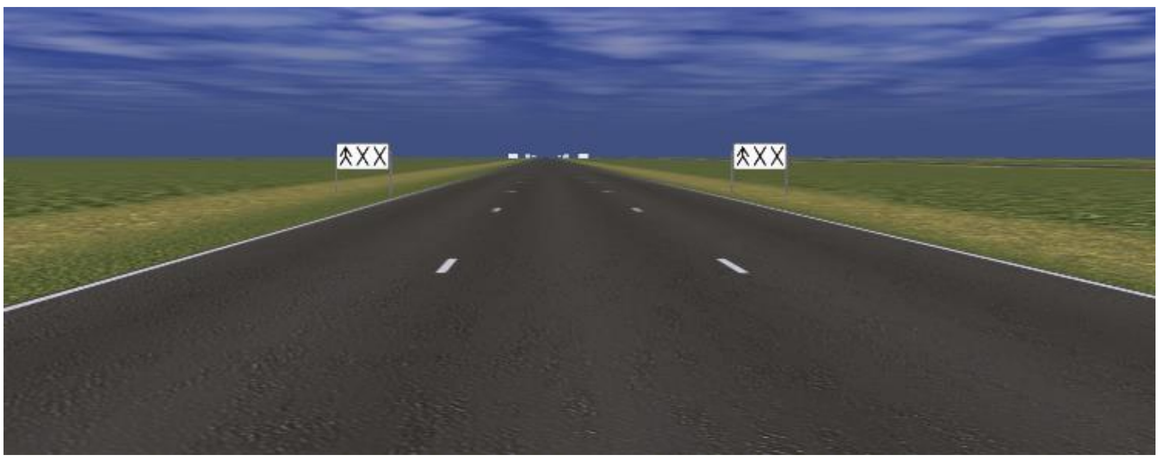

FIGURE 2. Screen capture of a lane change sign.

On either side of the track, road signs appeared and a chevron indicated the correct lane to move in to and two X's indicated the incorrect lanes (Figure 2). Participants were instructed to change lanes as quickly and efficiently as possible and as soon as they determined the correct lane to move into. The speed of the vehicle was fixed by the software at 60 kilometers per hour. Participants were instructed to press the accelerator pedal all the way to the floor and leave it there for the duration of the track. Driving was done with the left hand only, even when there was no secondary task.

Participants used their right hand to perform the secondary selection task for trials on which it was present.

The secondary task was displayed on a computer monitor situated to the right of the participant roughly 3 feet away (See figure 3).

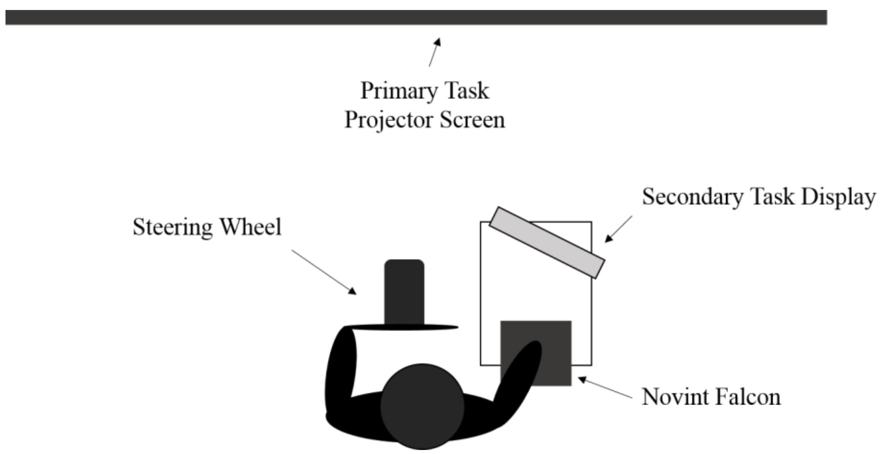

FIGURE 3. Top down diagram of the experimental layout.

Participants used the Novint Falcon force feedback enabled input device which allows for three degrees of freedom. However, similar to the studies conducted by Rorie et al. (2012, 2013) the device was limited to move only within the horizontal plane. The secondary task required participants to first select a green target located in the center of the display then select the red target, which appeared at varying locations around the display. As soon as participants clicked the red target, the starting target reappeared and the red target moved to a new position. The target selection task was completely self-paced. A self-paced secondary task was chosen because it was meant to represent a distraction in a vehicle, such as tuning the radio or answering the phone, which is completely voluntary and has nothing to do with driving. The secondary task display was approximately 20cm x 20cm and consisted of a black background overlaid with gray concentric circles (Figure 4).

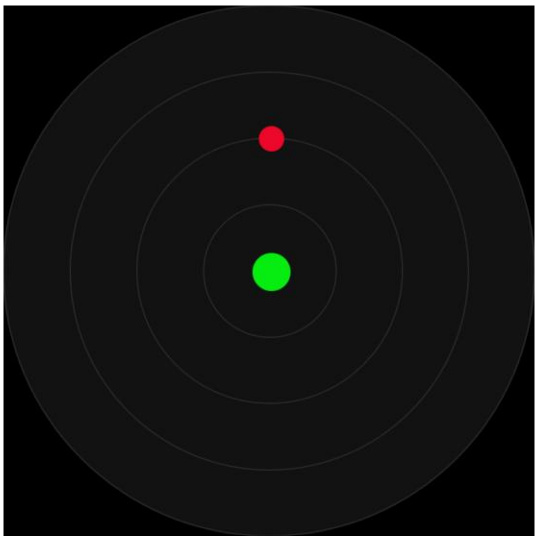

FIGURE 4. Screen capture of the secondary task display.

Red targets appeared in one of eight radial directions (0º, 45º, 90º, 135º, 180º, 225º, 270º, and 315º) with 0 degrees meaning that the target appeared directly above the green circle and 90 degrees meaning that the target appeared directly to the right of the starting circle. Targets could be positioned at one of two distances from the center (5 cm or 7.5 cm) and the size of the targets was held constant throughout the experiment. The starting target always had a radius of 0.75 centimeters and the ending target always had a radius of 0.5 centimeters.

Two force feedback models consistent with those used by Rorie et al. (2012, 2013) were used. One, based on a modified version of Newton's gravitational equation, was active during the time the cursor was outside of the target boundary ($\|d\| > r$) (Equation 1). This force pulled the cursor towards the center of the target and increased in magnitude as the square of the distance between the cursor and the center of the target ($\|d\|$) decreased. Two levels of the gravity constant (K_1) were used, 500 and 100 Newtons * pixels^2. Once the cursor was inside the boundary of the target ($\|d\| \leq r$), the gravity force was no longer active. At this point, the spring force became active. The spring force was based on the standard spring equation (Equation 2). It also pulled the cursor towards the center of the circle but increased as the square of the distance between the cursor and the center of the target ($\|d\|$) increased. Two levels of the spring force constant (K_2) were used, 0.2 and 0.05 Newtons per Pixel.

Newton's Gravitational Law Formula: $F = (K_1 * \|d\|^2)\ \hat{d}\ [when\ d > r]$ (1)

Spring Force Formula: $F = (K_2 * \|d\|)\hat{d}\ [when\ d \leq r]$ (2)

Experimental Design

The experimental design was a 2 (gravity force) x 2 (spring force) repeated measures design (shown in table 2). The four unique force conditions were presented in a counterbalanced order. In addition to the force feedback conditions, participants performed an experimental block in which no force feedback was present on the secondary task. Half of the participants performed the no force feedback condition first and the other half performed the no force feedback condition last.

TABLE 2. Independent Variables

Independent Variable	Levels
Gravity force constant	Low (100 Newtons * Pixel^2) High (500 Newtons * Pixel^2)
Spring force constant	Low (0.05 Newtons * Pixel) High (0.2 Newtons * Pixel)

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The dependent variables related to driving performance were the mean lane deviation and reaction time to the lane change sign. The mean lane deviation was measured in accordance with ISO 26022 and calculated by the lane change task software. Mean lane deviation was calculated for each track using the ISO 26022 standard. The program first creates an adapted path trajectory for each participant based on his or her baseline driving data. Then this adapted path trajectory is used as the basis for determining mean lane deviation.

Reaction time to a lane change sign was measured as the amount of time elapsed between when the sign appears on the screen and when the steering wheel angle reaches at least three degrees in the correct direction. The lane change software was configured to display the lane change indication on the sign when the vehicle was 80 meters away. The timestamp associated with this location was used as the stimulus onset time and compared to the timestamp at which the three degree threshold was reached. The difference between these two timestamps represents the reaction time.

The dependent variables for the target selection task were the average number of targets selected during a track, mean overall movement time, mean approach time, and mean selection time. The overall movement time was defined as the amount of time elapsed between when the participant selected the starting target, and when the participant selected the ending target. The approach time was defined as the amount of time elapsed between when the participant selected the starting target and when the cursor crossed the boundary of the ending target. The selection time was defined as the amount of time elapsed between when the cursor crossed the boundary of the ending target and when the participant clicked the button on the device to make the selection. Since the secondary task was self-paced, the total number of targets selected within an experimental block was also recorded. At the middle and end of each experimental block participants filled out a NASA TLX workload survey.

Procedure

Upon arrival, participants completed an informed consent form and filled out a demographics questionnaire which was used to determine eligibility to participate (Appendix A). After completing these forms, participants completed a baseline lane change task by driving three tracks without performing the secondary task. After completing the baseline task, participants were instructed on how to perform the secondary task and told to complete the secondary task when they were able to, and reminded that their primary task was the lane change task. Participants were then allowed to become familiar with the force levels being utilized on the current block by practicing the secondary task alone. Once participants were comfortable with the secondary task force levels, they drove six test tracks in groups of three while simultaneously performing the target selection task at their own pace. Participants were given a short break between each group of three test tracks at which point they filled out a NASA TLX survey (Appendix C). Once the participant had completed all five experimental blocks (4 blocks with unique force levels and 1 with no force), participants completed a final set of baseline runs in which no secondary task was presented.

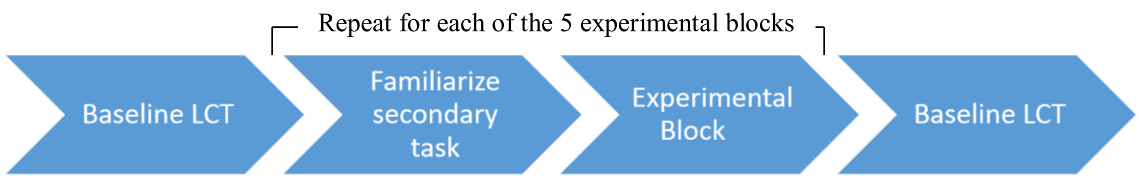

FIGURE 5. Graphical representation of the experimental procedure.

Each test track lasts approximately three minutes. Thus, an experimental block of six test tracks with breaks between every three tracks lasted approximately 30 minutes. On the first day participants filled out paperwork, completed a set of baseline runs, and two experimental blocks. On the second and final day, participants completed the remaining three experimental blocks and a final set of baseline runs. In total the study required approximately three hours to complete and participants were compensated at a rate of $10/hour for their participation. After completing the second day, participants were briefed on the purpose of the study and thanked for their time.

CHAPTER 3

RESULTS

This experiment was a 2 (gravity constant) x 2 (spring constant) within-subject design. Additionally, an experimental block during which no force feedback was enabled on the Novint Falcon was used a baseline condition. The first hypothesis was that performance on the primary driving task will be better when force feedback is enabled on the secondary task comparted to when there is no force feedback on the secondary task. To test this hypothesis, difference scores between each force condition and the baseline no-force condition were computed. Then, one-sample *t*-tests were used to test the null hypothesis that the calculated mean difference scores were equal to zero. If the difference scores are not equal to zero this would indicate significant differences in performance between the force-enabled conditions and the no-force condition.

The secondary hypothesis was that increasing the level of force feedback would also increase performance on the primary task. To test this hypothesis a 2 (gravity force) x 2 (spring force) within-subjects ANCOVA using the average weekly mileage data collected from each subject as a covariate was utilized to determine how the specific levels of gravity and spring force effected performance on the primary task. Average weekly mileage was chosen as a covariate because there was a moderate negative correlation between it and mean lane deviation on all force conditions ($r = -0.361$, $p = .124$) and no-force conditions ($r = -.385$, $p = .108$).

In order to interpret the results effectively, it is necessary to establish the fact that the secondary task did indeed interfere with the primary task. To do this, a one factor (secondary task vs no secondary task) repeated measures ANOVA was run on the TLX scores and reaction time data. Lane deviation was not analyzed in this way because the baseline driving data is built into the lane deviation calculation. Results showed that average TLX scores when driving alone ($M = 17.97$, $SE = 11.42$) were significantly lower ($F(1, 11) = 68.89$, $p < 0.001$) than TLX scores when the driving while performing the secondary task ($M = 48.54$, $SE = 15.18$). The results for reaction time followed a similar trend. When no secondary task was present, reaction time ($M = 759.17$ ms., $SE = 103.28$) was significantly shorter ($F(1, 11) = 25.036$, $p < 0.001$) than reaction time when the secondary task was present ($M = 1116.35$ ms., $SE = 318.27$).

Mean Lane Deviation

Mean lane deviation was calculated for each track using the ISO 26022 standard. The program first creates an adapted path trajectory for each participant based on his or her baseline driving data. Then this adapted path trajectory is used as the basis for determining mean lane deviation. This helps to build a more accurate representation of how driving performance differs when a secondary task is added for each individual driver.

It was hypothesized that performance on the mean lane deviation would be better when force feedback was applied to the secondary task, compared to when no force feedback was applied to the secondary task. To test this hypothesis, difference scores between each condition with force feedback and the baseline no force feedback condition were computed. These difference scores were then subjected to one-sample *t*-tests with the null hypothesis being that they were equal to zero. In other words, no difference between the no-force baseline condition and the force added conditions. Contrary to the original hypothesis, none of the difference scores were significantly different from zero (all *p's* > .218). The addition of force feedback did not reduce mean lane deviation when compared to the baseline condition.

TABLE 3. Mean Lane Deviation *t*-Test Results

Force Condition	*t*	*df*	Sig	Mean	Difference score
Gravity High Spring High	0.821	11	.429	0.521	0.017
Gravity High Spring Low	0.810	11	.435	0.514	0.023
Gravity Low Spring High	1.307	11	.218	0.498	0.039
Gravity Low Spring Low	1.006	11	.336	0.509	0.029

Test Value = 0

The secondary hypothesis was that as the magnitude of the force feedback increased, mean lane deviation would decrease. To test this hypothesis, the original deviation scores were subjected to a 2 (gravity) x 2 (spring) repeated measures ANCOVA using the number of weekly miles driven as a covariate. Again, contrary to the original hypothesis, there was no main effect of gravity or spring force on mean lane deviation and no significant interactions (all *p*'s greater than 0.115).

Reaction Time

Reaction time was calculated as the amount of time elapsed between when a sign first appeared on the track and when the participant's steering wheel reached an angle greater than three degrees in the correct direction. The first hypothesis was that adding force feedback in the secondary task would decrease reaction time to the lane change signs. To test this hypothesis, difference scores were computed between the baseline no-force condition and each force condition. The null hypothesis was that these difference scores were equal to zero. *t*-Tests revealed that only the force condition using the high gravity and high spring force constants resulted in a difference score significantly different than zero ($t\ (11) = -2.348$, $p = 0.039$).

TABLE 4. Reaction Time *t*-Test Results

Force Condition	*t*	*df*	Sig	Mean (ms)	Difference score (ms)
Gravity High Spring High	-2.35	11	0.039	1036.45	-79.9
Gravity High Spring Low	0.215	11	0.834	1133.79	17.43
Gravity Low Spring High	-1.28	11	0.228	1050.74	-65.61
Gravity Low Spring Low	-0.44	11	0.669	1102.23	-14.13

Test Value = 0

When both the gravity and spring force were at their highest level, reaction times were shorter than when no force feedback was enabled ($M = -79.9$ ms, $SE = 34.03$). All other force conditions were not significantly different from the baseline condition.

The secondary hypothesis was that as the magnitude of the force feedback increased, reaction times to the road signs would decrease. A 2 (gravity) by 2 (spring) repeated measures ANCOVA using the weekly number of miles driven as a covariate was utilized. Average weekly mileage was chosen as a covariate because there was a strong negative correlation between it and mean reaction time on all force conditions

(r = -0.456, p = 0.068) and no-force conditions (r = -.519, p = 0.042). There was no main effect of gravity; however, there was a marginally significant main effect of spring force (F (1, 10) = 4.34, p = 0.064).

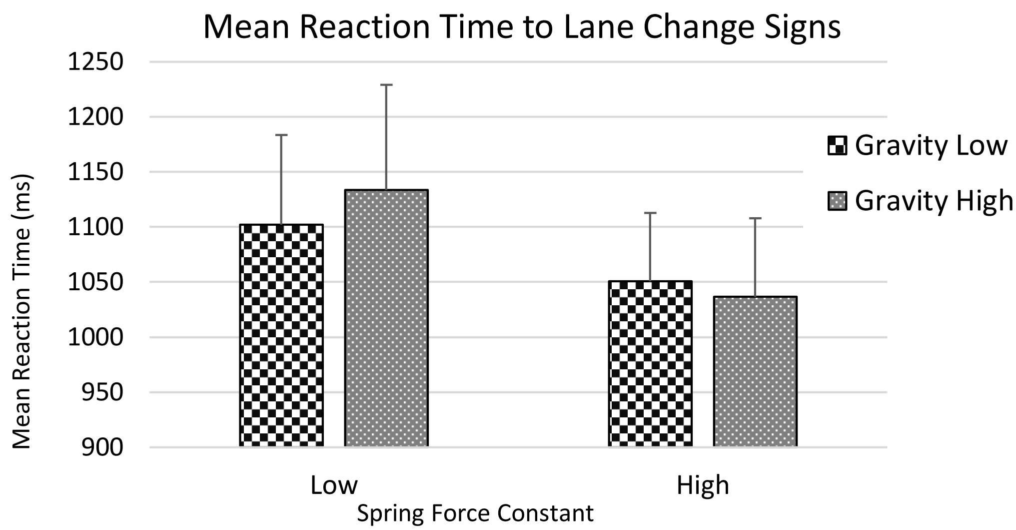

FIGURE 6. Mean reaction time by force constant. Error bars represent one standard error.

High spring force was associated with lower reaction times (M = 1043.594 ms, SE = 63.95) compared to reaction times with low spring force (M = 1118.0 ms, SE = 79.11). There was no significant interaction between the spring and gravity force.

Average Number of Targets Selected

The average number of targets selected on the secondary task throughout the course of one track was calculated for each force condition and the baseline no-force condition. Difference scores were then calculated between the force conditions and the baseline. One-sample t-tests were used to determine if the difference scores were significantly different from zero. Results of the *t*-tests show that the only force condition that resulted in a difference score significantly different from zero was when both the gravity force and spring force were at their highest levels (t (11) = 3.44, p = .006). When this combination of force constants was present on the secondary task participants selected 7.06 more targets on average during the course of each track compared to when no force feedback was present.

TABLE 5. Average Number of Targets Selected *t*-Test Results

Force Condition	*t*	*df*	Sig	Mean	Difference score
Gravity High Spring High	3.44	11	0.006	46.71	7.07
Gravity High Spring Low	0.645	11	0.532	41.78	2.14
Gravity Low Spring High	0.015	11	0.989	39.68	0.41
Gravity Low Spring Low	0.305	11	0.766	40.24	0.60

Test Value = 0

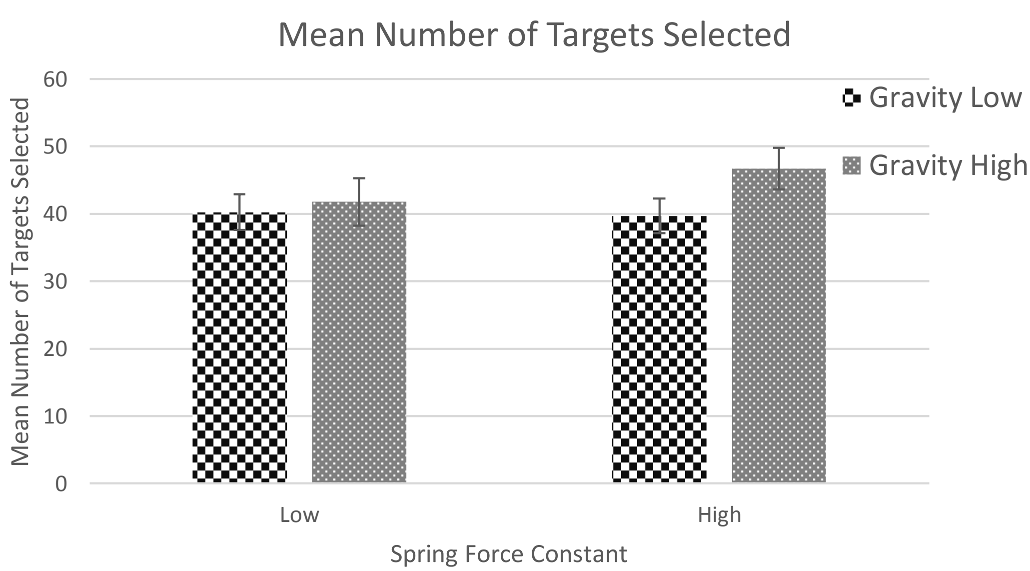

FIGURE 7. Mean number of targets selected. Error bars represent one standard error.

Next, a 2 (gravity) x 2 (spring) within-subjects ANOVA was used to determine if there were any main effects or interactions between the spring and gravity force constants on the average number of targets selected. There was a significant main effect of gravity force (F (1, 11) = 6.53, p = 0.027) such that when the gravity force constant was high participants selected significantly more targets on average (M = 44.24, SE = 2.94) than when the gravity force constant was low (M = 39.96, SE = 2.44). There was also a marginally significant main effect of spring force (F (1, 11) = 3.96, p = 0.072) such that the high level of spring force was associated with more targets being selected (M = 43.20, SD = 2.65) than the low level of spring force (M = 41.01, SE = 2.604) (See Figure 5). No significant interaction existed between gravity and spring force.

<u>Overall Movement Time</u>

Mean overall movement time for each target selected was measured as the time elapsed between when the participant clicked the starting target and when they made their final target selection. Difference scores between mean overall movement time for each force condition and the baseline no-force condition were calculated. One-sample *t*-Tests were then used to test the null hypothesis that these difference scores were equal to zero. Results revealed that all force conditions resulted in significantly lower overall movement times than the no-force condition (Table 3).

TABLE 6: Overall Movement Time *t*-Test Results

Force Condition	*t*	df	Sig	Mean (ms)	Difference score (ms)
Gravity High Spring High	-4.312	11	.001	994.63	-398.51
Gravity High Spring Low	-3.654	11	.004	1061.30	-331.85
Gravity Low Spring High	-3.229	11	.004	1145.75	-247.39
Gravity Low Spring Low	-3.767	11	.003	1131.48	-261.66

Test Value = 0

The four force conditions were then subjected to a 2 (gravity) x 2 (spring) repeated measures ANOVA. Results indicated a significant main effect of gravity (F (1, 11) = 15.99, p = .002) such that the high gravity force constant resulted in significantly shorter overall movement times (M = 1027.96 ms, SE = 74.25) than the movement times observed when the gravity constant was low (M = 1138.62 ms, SE = 83.55). No main effect of spring force was found and there was no significant interaction between spring force and gravity force.

Mean Approach Time

To better understand the influence of each force model (spring vs gravity) on target selection times, the target selection task was broken down into two segments, the approach time and the selection time. Approach time is defined as the duration between when the participant selects the starting target and when the cursor breaches the boundary of the ending target. Difference scores between each force condition and the baseline no-force condition were calculated for mean approach time. One-sample t-tests were used to test the null hypothesis that these difference scores are equal zero. Results showed that all force conditions resulted in significantly lower approach times than the baseline no-force condition (all $p < .003$).

TABLE 7. Movement Time *t*-Test Results

Force Condition	*t*	*df*	Sig	Mean (ms)	Difference score (ms)
Gravity High Spring High	-4.40	11	0.001	755.55	-384.63
Gravity High Spring Low	-4.00	11	0.002	805.58	-334,59
Gravity Low Spring High	-3.71	11	0.003	877.20	-262.98
Gravity Low Spring Low	-4.00	11	0.002	897.64	-242.54

Test Value = 0

To determine the effect of each force model separately, the four force conditions were subjected to a 2 (gravity) x 2 (spring) repeated measures ANOVA. Results revealed a significant main effect of the gravity force constant (F (1, 11) = 18.88, p = .001) such that when the gravity force level was high, approach times were significantly shorter (M = 780.56 ms, SE = 72.65) then the approach times when the gravity force was low (M = 887.42 ms, SE = 78.33). Again, there was no main effect of gravity force and no significant interaction between gravity and spring force on approach time.

<u>Mean Target Selection Time</u>

Target selection time was defined as the amount of time elapsed between when the cursor first breached the boundary of the final target and when the participant made their final selection. Again, to determine if any differences between the force conditions and the no-force condition existed, difference scores were computed and subjected to a one-sample *t*-test. The null hypothesis was that difference scores are equal to zero. Results of the *t*-tests showed that none of the force conditions resulted in a difference score that was significantly different from zero (all $p > .176$).

TABLE 8: Target Selection Time *t*-Test Results

Force Condition	*t*	*df*	Sig	Mean (ms)	Difference score (ms)
Gravity High Spring High	-1.16	11	0.27	239.08	-13.88
Gravity High Spring Low	0.28	11	0.79	255.71	2.75
Gravity Low Spring High	1.06	11	0.31	268.56	15.59
Gravity Low Spring Low	-1.45	11	0.18	233.85	-19.11

Test Value = 0

To investigate the effects of each force model on selection time separately, a 2 (gravity) x 2 (spring) repeated measures ANOVA was used. Results showed no significant main effects of either gravity or spring force and no significant interaction between the two force models on target selection time.

TLX Workload Data

After completing each block of 3 tracks, participants completed a NASA TLX workload survey. It was hypothesized that when force feedback was enabled on the secondary task, TLX scores would be lower than when no force feedback was enabled. To test this hypothesis, difference scores were computed between TLX scores on each force condition and TLX scores on the no-force condition. One-sample *t*-tests were used to test the null hypothesis that the difference scores were equal to zerp. Results indicated that difference scores for all but the condition on which gravity force was high and spring force was low were significantly less than 0 indicating lower TLX scores compared to the baseline scores.

TABLE 9. TLX Difference Scores *t*-Test Results

Force Condition	*t*	*df*	Sig	Mean	Difference Score
Gravity High Spring High	-2.472	11	.031	40.96	-7.58
Gravity High Spring Low	-1.779	11	.103	44.14	-4.40
Gravity Low Spring High	-2.623	11	.024	41.76	-6.79
Gravity Low Spring Low	-2.386	11	.036	43.47	-5.07

Test Value = 0

To determine how the individual force models effected TLX scores individually, a 2 (gravity) by 2 (spring) repeated measures ANOVA was conducted. Results indicated no main effect of gravity or spring force and no interaction between spring and gravity force.

CHAPTER 4

DISCUSSION

The purpose of the present study was to investigate performance differences on a standardized lane change task when a secondary target selection task either utilized various levels of force feedback or had no force feedback present. In previous research, the target selection task was performed in isolation and significant improvements to target selection performance were observed as the magnitude of force feedback increased. This study expanded on previous research in force feedback enabled input devices by examining its effectiveness in a dual task paradigm (e.g. Rorie et al., 2012, 2013 & Koltz et al., 2014). Specifically, the present study investigated whether or not adding force feedback to the secondary task could change performance on the primary task.

Participants were required to complete the standardized lane change task while simultaneously performing a task that required large amounts of visual resources to complete accurately. Since both the lane change task and the target selection task required visual input and manual output almost exclusively, they interfered heavily with one another. The hypothesis was that adding force feedback to the secondary task would reduce the interference between the two tasks resulting in increased performance on both.

Participants were instructed that their primary task was the lane change task and that they should always drive as accurately and safely as possible. Their secondary task was a target selection task similar to that used by Rorie et al. (2013) and was to be completed when they felt they could do so without impacting their driving. Driving performance was measured using the ISO 26022 standard mean lane deviation and the mean reaction time to the lane change signs placed on either side of the course. Performance on the target selection task was measured by the average number of targets selected, the average overall target selection time, the average movement time to the target, and the average selection time within the target. Finally, subjective workload ratings were gathered using the NASA task load index survey.

When considering approach time and overall movement time in the secondary task, the results of the present study were consistent with previous force feedback studies. For example, previous studies found that as the level of gravity force increased, approach time and overall movement time decreased significantly (Rorie et al., 2013, Koltz et al., 2014). The results of the present study are consistent with this finding.

Target selection time in the previous study was not consistent with past research. Rorie et al. (2013) and Koltz et al. (2014) both found that as the spring force increased target selection time decreased significantly. The present study found no significant main effect of spring force on target selection time. However, this may have been due to the relatively small number of target selections participants made during the course of the experiment. In fact, the difference in mean target selection time between the lowest level of spring force and the highest found by Rorie et al. was 9.66 ms. In the present study, the difference in mean target selection between the highest and lowest level of spring force was 9.04 ms.

In terms of primary task performance the results of the present study were contrary to the original hypothesis; adding force feedback to the secondary task did not reduce lane deviation in the primary task and had limited effects on the reaction time to the lane change signs. Reaction times to the lane change signs were shorter only when the force levels were at their highest. The results also showed that performance on the secondary task increased when force feedback was enabled. Participants selected more targets on average and selected them faster when the magnitudes of the force feedback were high. These results show that participants were task sharing appropriately based on the instructions given to them.

When the secondary task required a high degree of visual attention (i.e., when there was little or no force feedback), participants accepted lower levels of performance on the secondary task by selecting fewer targets on average in order to maintain a consistent level of performance on the driving task. As the force feedback increased and the secondary task demanded lower amounts of effort, participants were able improve performance on the secondary task without sacrificing primary task performance. In fact at the highest magnitude of force feedback, reaction time on the lane change task actually decreased. Assuming Wicken's multiple resource theory, these results indicate that force feedback was freeing up resources shared between the two tasks. It has been suggested that adding force feedback to a task reduces its visual processing load freeing up that system for other tasks (Akamatsu & MacKenzie, 1996). Since reaction time is partly dependent on the visual processing system, the results of the present study support the idea that force feedback reduces the load on the visual processing system.

The fact that mean lane deviation did not decrease when force feedback was enabled may be because the secondary task was self-paced and participants were told to only complete that task when they were able without sacrificing driving performance. This meant that while participants were moving between lanes, they could shift all of their attention to that task, abandoning the secondary task. Thus, participants could achieve a high level of performance regardless of the level of feedback enabled on the secondary task. Between lane changes, the driving task only required participants to drive straight down their lane. This required relatively little attention.

Overall the results of the present study suggest that applying force feedback to a secondary task in the context of distracted driving may provide a limited benefit to driving performance. However, decreasing the difficulty of a secondary task in a vehicle may have an undesirable effect. The NASA TLX data showed that participants felt as though the force feedback reduced the overall workload of the combined tasks. The feeling of reduced overall workload may encourage drivers to perform the secondary task more often than they normally would. When compared to any of the dual task conditions, the baseline driving only condition resulted in far better driving performance on all measures. Therefore, performing any secondary tasks should be discouraged in order to promote the best possible driving performance. Adding force feedback to a secondary task may help with driving performance in some circumstances but at the risk of encouraging more frequent distracting activities.

Limitations

The design of the present study had several limitations. The most crucial limitation may be that the force models were only active on the target and not the starting circle. This meant that, regardless of the level of force feedback, there was always a component of the secondary task in which no force feedback was active. After each target was selected, participants had to manually return to the center of the display with no force assistance. This likely reduced the overall impact of adding force feedback to the secondary task. It is possible that if the starting circle had had force feedback enabled, participants could have completed the secondary task by feel alone and never have to actually look at that screen. This could have further decreased reaction time and made a significant difference even at lower levels of force feedback.

The secondary task was completely self-paced. This allowed participants to only complete the target selection task when they knew they would not need to change lanes any time soon. While the intervals between lane change signs were not constant, variability was low and it was relatively easy to predict when the next lane change would be required. This allowed participants to complete as many target selections as they could between lane change signs then stop all together as they approached a sign. This is likely why mean lane deviation was not lower with force feedback. Participants were simply stopping the secondary task during the time that lane deviation was most critical. Had participants been required to continue performing the secondary task while making the lane change, a larger effect of force feedback may have been observed.

Another limitation may have been the lane change task itself. On its own, the task is relatively predictable and requires isolated moments of attention to perform accurately. A driving task that requires more focused attention such as following another vehicle that makes unexpected stops or navigating a more complex course would demand more constant attention. In this type of task, participants would not have been able to predict when they would need to shift attention away from the secondary task to maintain performance on the primary task. This may have better highlighted the effects of the force feedback at free resources.

Finally, like previous force feedback research dealing with target selection tasks, there was only a single target on the display at any given time. In a real world application there would be a number of force enabled features on the display that were not the intended targets. To accurately select the intended target, participants would be required to allocate more visual resources to the target selection task to identify and confirm the correct target was being selected. This would likely limit the effectiveness of the force feedback at reducing visual demand thus reducing its overall benefit.

Future Research and Design Recommendations

The findings of the present study show that force feedback has the potential to reduce the cognitive demands of a secondary task, freeing them for use on primary task performance. When considering the use of force feedback input devices in real world applications, the results of this study further support previous conclusions on which level of force feedback should be used. That is, using the highest level force feedback gain possible without inducing instability in the device provides the greatest performance benefit to the user. Further, the present study also showed that the higher the level of gain, the greater the benefit to the primary task. However, future studies will need to address the limitations of this study.

It will be necessary to determine the impacts of distractor targets in dual task situations. These distractors may reduce the overall effectiveness of force feedback models at reducing the visual load on the secondary task. Future studies should also address the self-paced nature of the secondary task used in the present study. Forcing participants to complete the secondary task at critical times during the primary task may reveal more evidence to support the benefits of force feedback in dual task situations.

Additionally, increasing the complexity of the primary task such that it is less predictable may also increase the magnitude of the effect of a force feedback enabled secondary task. For example, requiring drivers to navigate through a complex city while avoiding obstacles would dramatically reduce the predictability of the primary task.

Finally, other types of secondary task which could utilize force feedback need to be examined under dual task conditions. For example, it would be useful to examine more realistic tasks such as scrolling through a list of songs or using a secondary screen for navigation using some kind of haptic feedback to assist the user.

APPENDICES

APPENDIX A

DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire:

Participant Number_________

1) Birth Year (YYYY) _________
2) Gender

   Male Female
3) Age ______
4) Do you have a current driver's license?

   Yes No
5) How long have you had your driver's license? _____
6) How many years of driving experience do you have?

   ____
7) On average, how many miles do you drive per week ______
8) What hand is your dominant hand?

   Right Left
9) Do you have normal or corrected to normal vision?

   Yes No
10) Do you play video games (circle) [yes/no]
    a. If so, on average how many hours per week do you spend playing video games? _____
    b. On average, how many of your video game playing hours do you spend playing driving/racing games? _____

APPENDIX B

NASA TLX WORKLOAD SCALE

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Participant Num:	Task	Date

Mental Demand How mentally demanding was the task?

Very Low — Very High

Physical Demand How physically demanding was the task?

Very Low — Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low — Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX C

INFORMED CONSENT FORM

CONSENT TO PARTICIPATE IN RESEARCH

The Effects of a Force Feedback Enabled Secondary Task on Driver performance on a Simulated Lane Change Task.

You are asked to participate in a research study conducted by Martin Koltz B.S. Human Factors in Aviation University of Illinois, from the Psychology Department at California State University, Long Beach. Results of this study will contribute towards Martin's master's thesis project. You were selected as a possible participant in this study because you indicated that you had a valid driver's license, normal or corrected to normal vision, right handed, and at least 19 years old

PURPOSE OF THE STUDY

With an influx of recent automotive technologies such as navigation displays that require more and more cognitive resources on behalf of the driver an individual's ability to react promptly may be hindered because of this increase in workload. Therefore, it is important to determine whether these new technologies will permit drivers to react appropriately to emergency situations.

The purpose of this study is to investigate the effectiveness of a force feedback display applied to a secondary task at changing performance on a simulated standard lane change task.

PROCEDURES

If you volunteer to participate in this study, you will perform the following tasks:

- Use a driving simulator to complete a standardized lane change task (LCT). This will require you to use a steering wheel to control a simulated vehicle as directed by road signs placed along the simulated track. The simulated driving task will be projected in front of you on a large projector screen.
- At the same time, you may be required to use a force feedback enabled input device to select targets on a second computer monitor.
- After completing the lane change task and target selection task you will be asked to fill out a workload survey.

If you choose to participate, you will complete 5 experimental conditions that will each last approximately 30 minutes and 2 two baseline conditions which will last approximately 10 minutes. The study will be conducted in separate sessions each lasting no more than 1.5 hours. The total amount of time required to participate will be no more than 3 hours.

POTENTIAL RISKS AND DISCOMFORTS

The risks of participation in this study are minimal, and are not greater than those ordinarily encountered in daily life (e.g., playing a game on a computer).
Breaks will be taken at regular intervals to alleviate any discomfort from extended use of the input devices.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

There will be no direct benefits to participants however the results of the study will help us better understand how force feedback effects dual task performance.

PAYMENT FOR PARTICIPATION

Participants will be paid $10 per hour for participation for a total of $30 for 3 hours.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. Participation or non-participation will not affect your grade or any other personal consideration or right you usually expect. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which in the opinion of the researcher warrant doing so.

IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact Martin Koltz (310) 968-0462 or Dr. Thomas Strybel (562) 985-5035.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact the Office of University Research, CSU Long Beach, 1250 Bellflower Blvd., Long Beach, CA 90840; Telephone: (562) 985-5314. eMail: ORSP-Compliance@csulb.edu
SIGNATURE OF RESEARCH SUBJECT

I understand the procedures and conditions of my participation described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____

Name of Subject

____ _____________

Signature of Subject Date

REFERENCES

REFERENCES

Abbot, J.J., Marayong, P., & Okamura, A.M. (2007). Haptic virtual fixtures for robot-assisted manipulation. In: S. Thrun, H. Durrant-Whyte, and R. Brooks (Eds.), *Springer Tracts in Advanced Robotics: Vol. 28. Robotics Research* (pp. 49-64). Berlin, Germany: Springer.

Akamatsu M., & MacKenzie I.S. (1996). Movement characteristics using a mouse with tactile and force feedback. *International Journal of Human-Computer Studies, 45*, 483-493.

Allport, D.A., Antonis, B., & Reynolds, P. (1972). On the division of attention: A disproof of the single channel hypothesis. *The Quarterly Journal of Experimental Psychology, 24*, 225-235.

Chong, I., Mirchi, T., Silva, H., Strybel, T. (2014). Auditory and visual peripheral detection tasks and the lane change test with high and low cognitive load. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (pp. 2180-2184). Chicago, IL: Sage.

Dennerlein, J.T., & Yang, M.C. (2001). Haptic force-feedback devices for the office computer: Performance and musculoskeletal loading issues. *Human Factors, 43*, 278-286.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*, 381-391.

General Motors. (2013) *GM announces widest deployment of 4G LTE services in vehicles.* Retrieved from http://media.gm.com/media/us/en/gm/ news.detail.html/ content/Pages/news/us/en/2013/Feb/0225_4g-lte.html

Griffiths, P. G., & Gillespie B. R. (2005). Sharing control between humans and automation using haptic interface: Primary and secondary task performance benefits. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 47*, 574-590.

Hancock, P., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accident Analysis and Prevention, 35*, 501-514.

Just, M. A., Carpenter, P. A., Keller, T.A., Emery, L., Zajac, H., & Thulborn, K.R. (2001). Interdependence of nonoverlapping cortical systems in dual cognitive tasks. *Neuroimage, 14*, 417-426.

Knowles, W.B. (1963). Operator loading tasks. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 5*, 155-161.

Koltz, M.T., Rorie, R.C., Robles, J., Vu, K-P. L., Marayong, P., Strybel, T.Z., & Battiste, V. (2014). Effects of type and strength of force feedback on the path of movement in a target selection task. In *Human interface and the management of information: Information and knowledge design and evaluation.* (pp. 217-225) Heraklion, Crete: Springer.

Martens, M.H., & Van Winsum, W. (2000). Measuring distraction: The peripheral detection task. TNO Human Factors Research Institute, Soesterber, Netherlands.

Mcleod, P. A. (1977). Dual task response modality effect: Support for multiprocessor models of attention. *Quarterly Journal of Experimental Psychology 29*, 651-667.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psychological Review 86*, 214-255.

Park, S., Howe, R.D., & Torchiana D. F. (2001). Virtual fixtures for robotic cardiac surgery. In *Proceedings of the 4th International Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 1419-1420). London, England: Springer.

Pickrell, T.M., & Ye, T.J. (2013). *Driver electronic device use in 2011.* (Report No. DOT HS 811 719). Washington, DC: National Highway Traffic Safety Administration.

Previc, F.H. (1998). The neuropsychology of 3-D space. *Psychological Bulletin, 124*, 123-164.

Proctor, R.W., & Johnson, A. (2004). *Attention: Theory and practice.* Thousand Oaks, CA: Sage.

Reagan, M. A., Lee, J.D., & Young, K.L., (2009). *Driver distraction: theory, effects, and mitigation.* Boca Raton, FL: CRC Press.

Redelmeier, D., & R. Tibshirani (1997). Association between cellular-telephone calls and motor vehicle collisions. *The New England Journal of Medicine, 336*, 453-458.

Rorie, R.C., Bertolotti, H., Strybel, T., Vu, K-P.L,Marayong, P., & Robles J. (2012). Effect of force feedback on an aimed movement task. In *Proceedings of the 4th International Conference on Applied Human Factors and Ergonomics,* (pp. 633-642). San Francisco, CA: USA

Rorie, R.C., Vu, K.P-L., Marayong, P., Robles, J., Strybel, T. Z., & Battiste, V. (2013). Effects of type and strength of force feedback on movement time in a target selection task. In *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting.* (pp. 36-40). San Diego, CA: Sage.

Rosenberg, L.B. (1993). Virtual fixtures: Perceptual tools for telerobotic manipulation. In *Virtual Reality Annual International Symposium,* (pp. 76-82). Seattle, WA: IEEE.

Salvucci D.D., Markley D., Zuber M., & Duncan P.B. (2007). iPod distraction: Effects of portable music-player use on driver performance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* (pp. 243-250). New York, NY: ACM.

Scott J., & Gray, R. A. (2008). Comparison of tactile, visual, and auditory warnings for rear-end collision prevention in simulated driving. *Human Factors 50*, 264-275.

Tsang, P.S., & Vidulich, M.A. (1987). Time-sharing visual and auditory tracking tasks. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* (pp. 253-257). New York, NY: SAGE.

Van Erp Jan B.F., & Van Veen Hendrick, A.H.C. (2004). Vibrotactile in-vehicle navigation system. *Transportation Research Part F: Traffic Psychology and Behaviour, 7*, 247-256.

Vollrath, M., & Totzke, I., (1999). *In-vehicle communication and driving: An attempt to overcome their interference.* University of Wuerzburg, Germany: Center for Traffic Sciences (IZVW).

Wickens, C.D. (1981*). Processing resources in attention, dual task performance, and workload assessment*. University of Illinois, Urbana-Champaign, IL: Defense Technical Information Center.

Wickens, C.D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*, 159-177.

Wickens, C.D. (2008). Multiple resources and mental workload. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 50*, 449-455.