Individual Differences in Driving-Related Multitasking

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Abstract

We conducted an experiment with 22 participants to investigate the effect of secondary task presentation style on driving-related performance. Prior to the experiment, participants were presented with three cognitive ability tests and answered an online survey consisting of the Domain-Specific Risk-Taking Scale (DOSPERT), the Driver Behaviour Questionnaire (DBQ), and some demographic questions. The participants then performed a 1-D tracking (primary) task which simulated longitudinal control of a car. They also performed a vowel counting secondary task (counting the number of vowels in a list of multiple letters) under a variety of conditions. These conditions combined different modalities (audio/visual), presentation styles (simultaneous/sequential), task complexity (the number of distractors), and list lengths. We discuss the experimental results in terms of the impact of individual differences, in risk tolerance and cognitive ability, on how the tasks were performed.

Introduction

With the adoption of increasingly complex information systems in passenger vehicles, interface designers are being asked difficult questions concerning how large quantities of information can be presented to the driver without creating unsafe levels of distraction. A naïve view of Multiple Attentional Resource Theory (Wickens, 1980) would suggest that since driving tasks are primarily visual in nature, then auditory interfaces should be used to avoid overloading visuo-spatial attentional resources. However, this issue is complicated by the existence of key differences in the ways that humans attend to and process different sensory modalities. For example, audio is an inherently "streaming" (time-dependent) medium. Thus the sequential acquisition of auditory information may sometimes be less efficient than the more simultaneous acquisition of visual information. Furthermore, sequential processing of speech may create a working memory load, as appears to happen with some text-to-speech interfaces (Strayer, 2012).

The research reported here sought to examine how people with different levels of cognitive ability and different levels of awareness of, and tolerance towards, risk, deal with the demand of carrying out a driving related task in the presence of a distracting secondary task.

The research questions addressed in this paper were:

- How do cognitive ability and style of presentation of the secondary task affect attention towards the primary task?
- How, if at all, do attitudes towards risk affect how much visual attention people pay to the primary task, and does this effect depend on cognitive abilities?

This question was motivated by the assumption that individual differences in attitude and behavior towards risky situations may affect the allocation of visual attentional resources while driving. We also assumed that individual differences in cognitive ability would affect multitasking performance, as we have found in our previous research (Mizobuchi et al. 2011, 2012). Thus, we designed an experiment in which participants performed dual-tasks with different secondary task conditions. Prior to the experiment, we measured participants' risk tolerance (attitude and behavior towards risky situations) and cognitive abilities, using methods explained in the next section.

Method

Three Steps of the Experiment

1. Online questionnaire

Forty-four people (Male=30, Female=14, aged from 18 to 34, *Mean*=24.68, *SD*=4.46 years-old) were recruited through invitations that were posted on the University of Toronto campus, sent to university e-mail lists, advertised on the Internet, and presented to a class. These participants answered an online survey consisting of the Domain-Specific Risk-Taking Scale (DOSPERT) and the Driver Behaviour Questionnaire (DBQ).

The DOSPERT, originally developed by Weber et al. (2002), is a psychometric scale that assesses risk taking in five decision domains: financial (separately for investing versus gambling), health/safety, recreational, ethical, and social. Respondents to the instrument rate the likelihood that they would engage in domain-specific risky activities. In this research, we used the revised DOSPERT with 30-items as presented by Blais et al. (2006).

The DBQ, originally developed by Reason et al. (1990), measures self-reported driving style and investigates the relationship between driving behaviour and accident involvement. In this study, we used a version of the DBQ adapted for use in the United States (Reimer et al., 2005), which was deemed to be more appropriate for our Canadian participants.

Twenty-two of the 44 respondents for the online questionnaire went on to do the following cognitive ability test and dual task experiment. The composition of this 22-person sample was determined by the following constraints. First, respondents had to express a willingness to participate further steps. Second we wanted the sample to be relatively balanced for gender. The sample for the follow-on studies was chosen so that it included at least 10 females. Subject to the first two constraints noted above, the final set of 22 participants was chosen so that people had more extreme (high/low) scores on the DOSPERT and DBQ. This created a group with contrasting risk tolerances intended to make tests of risk-related effects more sensitive. The resulting sample had twenty-two (Female=10, Male=12) participants between 18 and 33 years old (*Mean*= 25, *SD*= 4.6). All participants held a driver’s license or learner’s permit and were judged to be proficient in English.

2. Cognitive ability test

Prior to the experiment, the 22 participants performed three cognitive tests to measure their ability on three Central Executive (CE) functions (shifting, updating, and inhibition). These three functions were chosen based on Miyake et al.’s (2000) findings concerning mappings between tasks and CE functions. Tyey carried out various types of cognitive test on 137 participants. Confirmatory factor analysis (CFA) and structural equation modelling (SEM) showed that much of the variance in cognitive task performance could be explained by three CE functions (inhibition, shifting, and updating) that are moderately correlated with one another, but are also clearly separable. We selected three tasks that were closely related to the tasks that Miyake et al found were strongly related to inhibition, shifting, and updating respectively.

(1) Stroop test (Inhibition task): Six color-related words ('black', 'white', 'yellow', 'orange', 'purple', and 'green') were presented in one of the six corresponding font colors individually and at random. There were 36 possible word-font color combinations. On each trial, three color names (response alternatives) were presented in black at the bottom of the display. The participant's task was to respond with the color in which the stimulus word was written, by pressing a corresponding key. The three response alternatives were mapped to the left arrow key, down arrow key, and right arrow key, respectively.

(2) Color monitoring test（Updating task): Participants were shown blue, yellow and red circles (8cm in diameter) one at a time for 500ms in randomized order with an inter-stimulus interval of 2500ms. The task was to respond by pressing a down arrow key when the third instance of each circle color was presented (e.g., after seeing the third blue/yellow/red circle), which required participants to monitor and keep track of the number of times each color had been presented. For example, if the sequence was ''blue, red, yellow, yellow, red, blue, *yellow, blue, red*'' then the participant should have responded to the third blue, yellow and red circle (italicized). In order for momentary mental lapses to have less impact on task performance, the circle count for each color was automatically reset to 0 if the participant made a key press for that color, and participants were informed of this feature before starting the task. Prior to completing the trial blocks, participants received a practice session, which continued until they made 3 correct responses.

(3) Wisconsin Card Sort Test (WCST; Shifting task): In this task, four stimulus cards were displayed as images on a computer screen. The objects on the cards could differ in color, quantity, and shape. The participants were then shown an additional card and were asked to choose which one of the four original cards conformed to the same category as the additional card. The selection was made by clicking on one of the four original cards with the mouse. As the classification rule was not provided to the participants, they had to guess the rule. They did this based on the pattern of feedback provided to them ("correct" or "incorrect"), after they chose one of the four cards to match with the additional card. In this experiment, the classification rule changed after 10 correct responses under the rule. The task was finished when a participant completed 8 different rules or 128 trials, whichever came earlier. We used the number of perseveration errors as the performance measure based on our previous research (Mizobuchi et al., 2012)

3. Dual-task experiment

Participants performed a 1-D tracking (primary) task which simulated longitudinal control of a car. They also performed a vowel counting secondary task (counting the number of vowels in a list of multiple letters) under a variety of conditions. The various conditions combined different modalities (audio/visual), presentation styles (sequential /simultaneous), task complexity (the number of distractors), and list length.

Estimation of Distraction

Two methods were used for estimating the amount of visual distraction. The first (direct) method was to observe the proportion (and duration) of time that people were looking away from the primary task monitor. The second (indirect measure) was the variability (standard deviation) of the throttle input for the primary task. Our reasoning was that if people were visually focused on the primary task, then they would be able to track and control the size of the rectangle more smoothly, leading to relatively consistent throttle inputs. On the other hand, if they were distracted from the primary task and returned to it to find the rectangle (almost) out of bounds then they were be likely to make sudden changes in acceleration to remediate the situation. Thus variability in throttle input might also be a proxy for visual distraction.

Apparatus

Information was presented visually on up to two LCD monitors and auditorily through computer speakers. Data was collected using pedals from a Logitech Driving Force GT game controller and with a standard US Keyboard. In addition, a two-camera Remote Eye-Gaze Estimation (REGT) system (Guestrin et al. 2007) collected eye gaze data throughout the experiment. The arrangement of the equipment is shown in Figure 1.

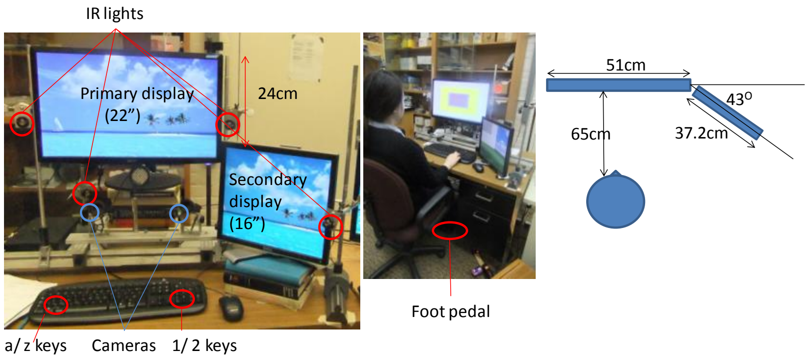

Figure 1 Experiment settings.

Tasks

The experiment consisted of a pedal tracking (primary) task, and a simultaneously performed vowel counting (secondary) task.

Primary task (Pedal tracking task)

We used the same pedal tracking task as in our previous research (Mizobuchi et al., 2012). This task was designed to simulate the maintenance of inter-vehicle distance on roadways, as originally proposed by Uno and Nakamura (2010). They reported that, in comparison among a lateral tracking task with a steering-wheel, a longitudinal tracking task with a foot pedal and a detect response task, performance of the pedal tracking task was most sensitive to different levels of difficulties of both auditory and visual secondary tasks. In the pedal tracking task, a target rectangle in blue (analogous to a car ahead) and a frame-shaped area in yellow (the ideal following distance) were presented on the primary monitor (M1). The target rectangle fluctuated based on a mixed sign wave signal. As a participant tapped/released the foot pedal, the target rectangle expanded/shrunk accordingly. The participants' goal was to keep the outer edge of the target rectangle inside the yellow area by manipulating a single foot pedal. The target rectangle turned to red when it went outside the yellow area as shown in Figure 2.

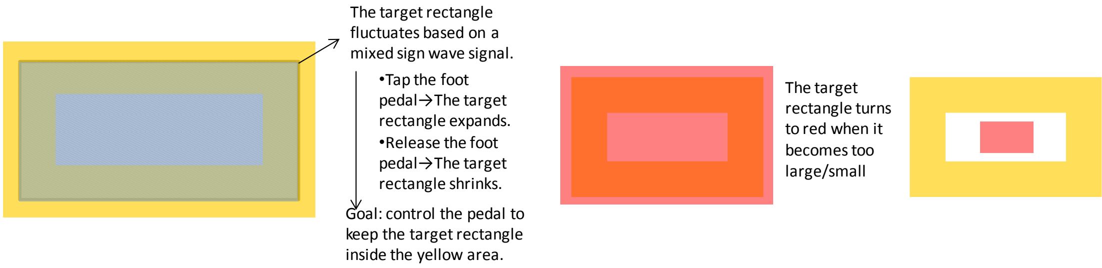

Figure 2 Pedal tracking task visualizations.

To simulate the control dynamics of adjusting accelerator input while following a lead vehicle driving at variable speed, the size (side length) of the target rectangle (D) was defined by equation (1).

$$D = D_0 + \int(V_0 + \int(S_f - L_t)dt)dt \qquad (1)$$

Initially D_0 was equal to half the width of the acceptable area (yellow area). V_0 equalled 0 km/h and dt was 0.1sec. S_f represented the fluctuating signal while L_t was a percentage of the first order lag of the throttle opening. D was the second-order integral of the difference between the fluctuating signal (corresponding to the acceleration of the car in front) and the control signal (corresponding to the acceleration of one's own car; the first order lag of the throttle opening %). The fluctuating signal was generated from a mixture of four sine waves.

Secondary task (Vowel counting task)

In this task, participants were presented with a sequence of letters in list form (e.g., "AABA") and instructed to count the number of vowels in the list before indicating whether the total number of target items was odd or even by pressing a corresponding key ("1" key for Odd and "2" key for Even). Participants were cued to respond either by a change in stimulus appearance (visual conditions) or voice (audio condition).

The experiment consisted of twelve conditions, which varied according to presentation style (the stimuli were presented sequentially in audio, sequentially in visual, or simultaneously in visual), list length (4 vs 12 letters), and number of distractors ("AB" vs "AIUCFM"). The capital letters "AIUCFM" were chosen based on an analysis of audio confusability (Conrad, 1964; Hull, 1973) and visual (Townsend, 1971; Gilmore, Hersh, Caramazza, & Griffin, 1979). Each condition consisted of eight trials. Within the twelve conditions, the combinations of presentation style, list length, and number of distractors were randomly ordered.

The inter-item interval (for sequential conditions) was set to 1s and the inter-trial interval was 2s. Participants had up to a maximum of 3s to select a modality and up to 7.5s to answer whether the total number of vowels was even or odd. Across all conditions reaction times were recorded from the moment that the final stimulus was presented.

Procedure and Incentive Structure

Participants were run in the experiment individually. First, they were introduced to the primary (pedal tracking) task and given time to practice. Next, they were introduced to the secondary (vowel counting) task and given time to practice each presentation style with 4 item lists and with different numbers of distractors. Then, the tasks were combined to allow practice with 12 item lists, in both modalities, with multiple distractors (AIUCFM). After calibrating the Eye-Tracking System, the participants performed both the primary and secondary task simultaneously under 12 counter-balanced conditions that consists of eight trials each. During the experiment, participants were encouraged to take short breaks. Each experiment session took approximately 90 minutes for each participant. To promote engagement with both tasks equally at all times, we told participants that they would be awarded based on combined primary and secondary task performance with an emphasis on accuracy. Prior to the experiment the research protocol was approved by the University of Toronto Research Ethics Board.

Results

The analysis looked at the relationship between risk perception, cognitive ability, and performance of the primary and secondary tasks.

Cognitive Abilities and Eye Gaze

To examine whether there was a relationship between cognitive abilities and presentation style (of the secondary task) on eye gaze patterns, we carried out two stepwise entry regression analyses in which the dependent variables were (a) the mean percentage of time that a participant viewed the primary display (Monitor 1: M1) in a session (M1 gaze rate) and (b) the mean (per condition) maximum dwell time on the secondary display (Monitor 2: M2) by each participant (M2_MaxDwell_mean). The predictor variables in these analyses were CE ability test scores: accuracy and response time of correct response (CRT) of a color monitoring test (updating); a Stroop test (inhibition); the number of completed trials and the number of perseveration errors of WCST (shifting).

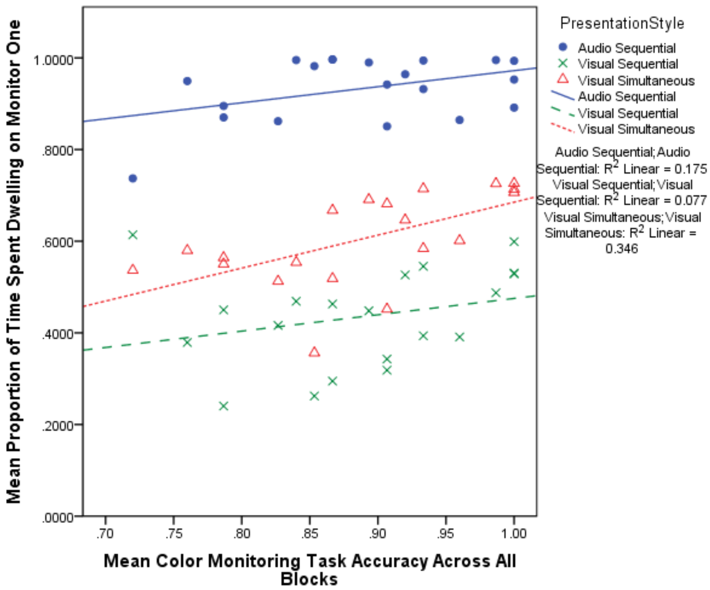

Figure 3 The relationship between updating ability and mean percentage of time spent dwelling on Monitor 1 (M1Gazerate) for the each of the three presentation styles.

Figure 3 shows that while there was a tendency for the proportion of time spent looking at the primary monitor (M1) to increase with updating ability, this tendency was most pronounced with the visual simultaneous presentation style, where the slope of the linear fit was significant, $F[1,18] = 9.54$, $p < .01$ (Table 1). As can be seen in Figure 3, simultaneous (versus sequential) visual presentation of information on a secondary task generally facilitated visual attention to the primary task, and this benefit was greater for people with higher updating ability. Table 1 shows a summary of the regression analysis results.

Table 1 Results from individual linear regression modelling of the effects of updating ability measures on M1Gazerate.

	Audio			Visual Sequential			Visual Simultaneous		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Updating Accuracy	0.35	0.18	0.42	0.36	0.29	0.28	0.72	0.23	.59**
R^2		0.18 (p = .067)			N.S.			0.35**	

Note: *p < .05 ** p < .01 *** p < .001

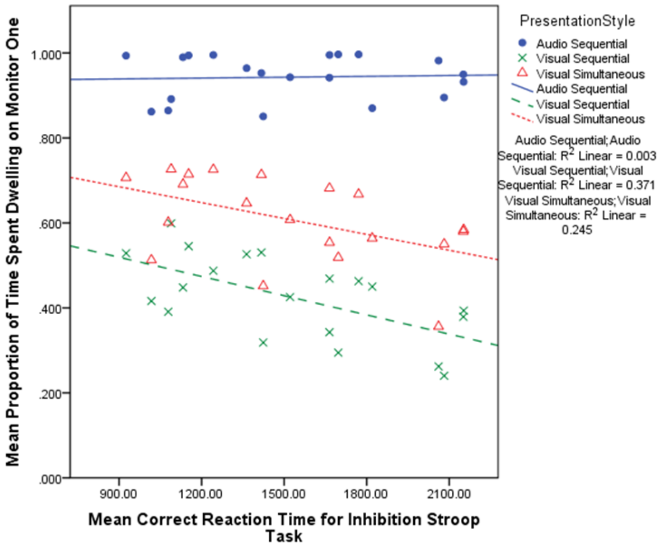

Figure 4 The relationship between inhibition ability and mean percentage of time spent dwelling on Monitor 1 (M1Gazerate).

Figure 4 shows a similar tendency for greater attention to the primary task monitor for participants with greater ability on a CE function, in this case inhibition ability (note that lower reaction times in the inhibition task were indicative of increased inhibition ability). As with updating ability, higher inhibition ability increased attention to the primary task in the visual sequential condition $F[1,18] = 7.14$, $p < .05$, but in contrast to the results for inhibition ability it also increased attention to the primary task in the visual simultaneous condition, $F[1,18] = 5.94$, $p < .05$. Table 2 shows a summary of results for the corresponding regression analyses.

Table 2 Results from individual linear regression modelling of the effects of Inhibition ability measures on M1 Gaze rate.

	Audio			Visual Sequential			Visual Simultaneous		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Inhibition_CRT	-1.03E-06	4.11E-05	-0.01	-1.43E-04	5.35E-05	-.53*	-1.27E-04	5.20E-05	-.50*
R^2		N.S.			0.28*			0.25*	

Note: *p < .05 ** p < .01 *** p < .001

Pedal Tracking Performance

We examined the effect of the experimental conditions on the accuracy of the pedal tracking task. First, we calculated the percentage of time when the target rectangle was inside the acceptable area (target-in rate) as a dependent variable. The target-in rate was very high in general, and likely due to this ceiling effect we did not find any significant effect of conditions. Then we carried out analysis of the numbers of participants who made "out-of-the-acceptable-area" errors at least once in a session. The result showed a significant effect of presentation style ($F[2, 42]=3.60$, $p<.05$) and list length ($F[1, 21]=8.67$, $p<.01$). A post-hoc analysis (Tukey's LSD analysis) showed a significant difference in the out-of-the-area error rate between the visual-sequential and visual-simultaneous conditions (Figure 5). Thus the adverse effect of sequential presentation of the secondary task (visually) was reflected not only in less visual attention to the primary task, but also in a key measure of primary task performance.

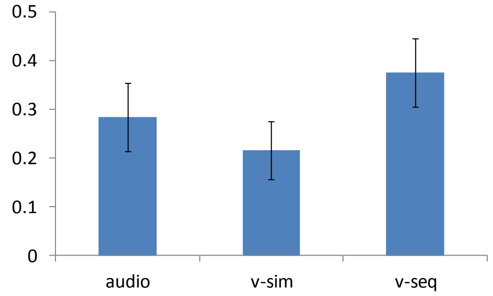

Figure 5 The rate of participants who made out-of-the-area errors

To further investigate the effect of individual differences on attention to the primary task, we also carried out stepwise entry regression analyses using the risk-related measures as predictors:

- DOSPERT scores: total score of all items, summed scores of financial_investment, financial_gambling, financial_combined, health_safety, and recreational items.
- DBQ scores: total score of all items, summed scores of errors, lapses, and violations.

We carried out stepwise entry regression analyses in which the dependent variable was the standard deviation of the throttle input, and the predictor variables were the total DOSPERT and DBQ scores, as well as the measures of cognitive ability used in the analyses reported above.

The best fitting regression model ($p<.001$) contained an inhibition ability measure, Acc_inhib (s-beta=.66, $p<.001$), an updating ability measure, CRT_updating (s-beta=.27, $p<.05$) and the DOSPERT_total risk measure (s-beta=-.40, $p<.005$). The model explained 76% ($r=.87$) of variance in mean SD of pedal input. People who were sensitive to risks and who had lower inhibition and updating ability operated the pedal in a smaller range, while people with higher ability in inhibition operated the pedal in a larger range regardless of their DOSPERT score.

Secondary Task Performance

Since reaction times in sequential vs. simultaneous presentation conditions were not comparable, only accuracy results are reported here.

Figure 6 shows the mean accuracy for the secondary tasks, with a generally high level of accuracy being observed. Repeated measures within-participants 3 (presentation style) x 2 (distractors) x 2 (list length) factorial ANOVA was conducted to test the differences amongst conditions. The results showed a significant main effect of list length ($F[1,21] = 14.5$, $p<.01$) and distractors ($F[1, 21] = 21.6$, $p<.001$) indicating lower accuracy in conditions with longer lists and more distractors. There was also a significant interaction between presentation types and list length ($F[2, 42] = 3.5$, $p<.05$) indicating a stronger impact of list length on sequential conditions than on simultaneous conditions.

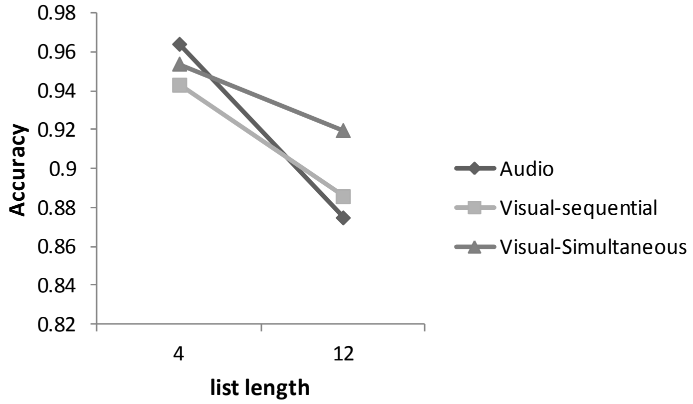

Figure 6 **The Effect of the interaction between presentation style and list length on Accuracy of the secondary task.**

We also investigated the relationship between individual differences and the secondary task performance. We carried out stepwise entry regression analyses in which the dependent variables were the mean accuracy of the secondary task, and predictor variables were the same variables as used in the analysis in the preceding section.

The best fitting model ($p<.005$) contained WCST_Perrors (s-beta=-.66 $p<.005$) DOSPERT_recreational (s-beta=.53, $p<.005$) and DBQ_lapses (s-beta=.38, $p<.05$) and it explained 59% ($r=.77$) of the variance in mean accuracy of the secondary task. Thus, people with higher shifting ability (i.e., a smaller number of perseveration errors) were more accurate in the secondary task. Stronger sensitivity to risks and reported risky behavior also predicted higher accuracy in the secondary task.

Discussion

The methodology used in this study was designed to examine the impact of distraction due to a secondary task. As expected, visual presentation was significantly more visually distracting (in terms of gazing away from the primary task monitor) than audio presentation. Primary task performance (in terms of pedal-tracking accuracy) with visual-simultaneous was neither better nor worse than that for audio presentation in both the pedal tracking (primary) and secondary tasks. However, not only was visual sequential presentation of the secondary task more distracting to the primary task, but performance on the secondary task was also worse in the visual sequential condition.

Thus sequential presentation of visual information should probably be avoided when adding information technologies in vehicles as it seems likely to have a damaging affect not only on the secondary task but also on the primary (driving) task.

How do cognitive ability and style of presentation of the secondary task affect attention towards the primary task?

We measured attention towards the primary task both in terms of the proportion of time spent gazing at the primary monitor, and in the variability in throttle use. We would expect that a person who was attending closely to the primary task would have a relatively constant level of throttle input. On the other hand, someone who was more distracted would tend to let the primary tracking task get closer to the extreme values (bordering on being out of range) leading to greater variability in throttle input as larger corrections were needed.

As expected, there was more visual distraction when the secondary task was presented visually, and this affect was greater when the visual stimuli were presented sequentially rather than simultaneously. This effect was moderated by updating ability, with the secondary task tending to be less distracting (as measured by M1 gaze rate) for people with higher updating ability, particularly when visual sequential presentation was used. A similar moderating effect was found with inhibition ability, except that the benefit of high inhibition ability in allowing a higher proportion of gazing on the primary monitor was found for sequential, as well as simultaneous, visual presentation.

How, if at all, do attitudes towards risk affect how much visual attention people pay to the primary task and does this effect depend on cognitive abilities?

We found that people who were measured as being sensitive to risks manipulated the pedal in a smaller range and spent more time viewing the primary task monitor.

There was an interesting dissociation between the three central executive functions in this study. While attention to the primary task was influenced by inhibition and updating ability, the influence of shifting ability seemed to be largely limited to secondary task performance in this study.

Conclusions

NHTSA Guidelines (2012) recommend that devices and tasks be designed so that they do not require a glance duration of more than two seconds away from the road. In our experiment, median glance duration was quite a bit shorter than that recommended amount (ranging between 600 and 900ms.) However, distribution of glance duration was positively skewed with the maximum glance duration on the secondary task monitor in visual conditions being greater than 8 seconds in the worst case (v-seq12AB). This should be taken into account when designing visual user interfaces for in-vehicle systems. As discussed by Horrey and Wickens (2007), the unsafe conditions that are likely to produce a motor vehicle crash reside not in frequently occurring conditions (e.g., near the centre of the distribution), but rather in the tails of the distribution.

The take home message from this study is that people with higher cognitive ability were able to attend to the primary task more, without negatively impacting their performance on the secondary task. The visual sequential style was the most distracting form of visual presentation, both in terms of reducing the amount of time spent looking at the primary task monitor, and in terms of increase the amount of variability in operating the primary task throttle. There was also a tendency for people with low risk awareness to be more distracted by the secondary task.

While higher inhibition and updating ability seemed to help people with selective attention i.e., focusing on the primary task), this increased attention to the primary tasks did not result in lower secondary task performance. Instead, secondary task performance was associated with shifting ability, with higher shifting ability leading to better secondary task performance.

We are currently in the early stages of explicating the role of cognitive abilities in determining how people react to distracting secondary tasks within vehicles. We believe that the research reported in this paper has identifed some useful presuppositions or hypotheses for future research. Secondary tasks are likely to be more distracting for people with lower cognitive abilities and amongst those people, those with a greater awareness of risk are more likely to maintain their focus on the primary task. In the vowel counting task that we used sequential presentation of the letters in the task was found to be harmful. Further research is needed with more complex (and possibly more ecologically valid) tasks to see whether sequential presentation of information in a secondary task is inherently more distracting or if the distraction is specific to the kind of secondary task that we used in this study. The present results also provide further evidence that it is necessary to consider the impact of different central executive functions rather than ascribe differences in performance to more general constructs such as working memory or mental workload. In the study reported here, inhibition and updating ability affected the amount of attention paid to the primary task, while shifting ability affected performance on the secondary task.

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