SHIFTING BETWEEN COGNITIVE AND VISUAL DISTRACTION: THE IMPACT OF COGNITIVE ABILITY ON DISTRACTION CAUSED BY SECONDARY TASKS

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Summary: We conducted an experiment in order to investigate impacts of central executive (CE) functions and modality of secondary task presentation in a dual-task experiment. We found that shifting ability, out of three major CE functions (inhibition, shifting, and updating) was particularly important in determining whether primary (pedal-tracking) task performance was better in the presence of auditory, vs. visual, presentation of the secondary task.

INTRODUCTION

New in-vehicle applications have potential impacts on driving safety. More tasks compete for the driver's attention, distracting even as they provide benefits (e.g., navigation support). Do individual differences in central executive functions (major components of cognitive ability) moderate the impacts of distraction and also influence the decision as to which modality should be used to present secondary tasks while driving? The multiple attentional resource theory (Wickens, 2002) approach might suggest using auditory presentation of secondary tasks to avoid overloading visual attentional resources. However, auditory presentation of secondary task information may lead to cognitive distraction by creating a greater load on working memory, since auditory information has to be integrated over time to infer meaning. Thus there is a design tradeoff, with auditory presentation of secondary tasks tending to create cognitive distraction, and visual presentation tending to create visual distraction.

Cognitive and visual distraction created by new interactive technologies and applications in vehicles may lead to inattention to the primary driving task, and inattention is known to increase the risk of accidents (Klauer et al., 2006). In this research, we consider three main central executive (CE) functions in working memory: "inhibition", "shifting", and "updating" (cf. Miyake et al., 2000). Mizobuchi et al. (2011) found that inhibition, updating, and shifting were all involved when carrying out device operation during simulated driving. These CE functions are presumably also involved in the driving task (e.g., updating one's knowledge of where the vehicle is relative to the roadway; switching attention between the roadway ahead and views in mirrors; inhibiting routine driving modes when faced with traffic signals, road signs, or a stopped school bus). How do differences in cognitive ability affect ability to drive while performing cognitively loading secondary tasks?

Baumann et al. (2008) assessed the effect of CE load on driving performance (time to collision and driving speed). They found that participants received less benefit from a warning signal when they had to perform a running memory task. They concluded that the central executive component of working memory is strongly involved in the construction of situation awareness. Mäntylä et al. (2009) also examined the relationship between CE function and driving performance. In their experiment, high school students completed a simulated driving task and six experimental tasks that tapped the three CE functions of inhibition, shifting, and updating. Their results showed that updating ability was a significant predictor of performance on a Lane Change Task (LCT) while doing simulated driving. Thus earlier research has established a role of CE functions in moderating driving performance distracted by secondary tasks. Our research sought to extend these results to incorporate the impact of secondary task modality.

METHOD

We screened 102 people on three tasks, a Stroop task (inhibition), a colour monitoring task (updating), and the Wisconsin Card Sorting Test (WCST; shifting). Thirty-four of these people then participated in the main experiment. People were chosen so as to cover a variety of different profiles in terms of shifting, updating, and inhibition scores. The selected participants consisted of 20 males and 14 females, aged from 17 to 64 years old (*M*=42.9, *SD*=13.2).

Design

The experiment was a within-participant design with 12 conditions (2 primary tasks x 3 CE functions x 2 modalities). Only results for the pedal tracking task will be reported here. Results for the second primary task (a target detection task) will be reported elsewhere.

Pedal tracking task

This task was designed to mimic driving behind a lead vehicle. The task was based on a pedal-tracking task used by Uno and Nakamura (2010). A target rectangle in blue (corresponds to a car in front) and a frame-shaped area in yellow were displayed on the main display (Figure 1).

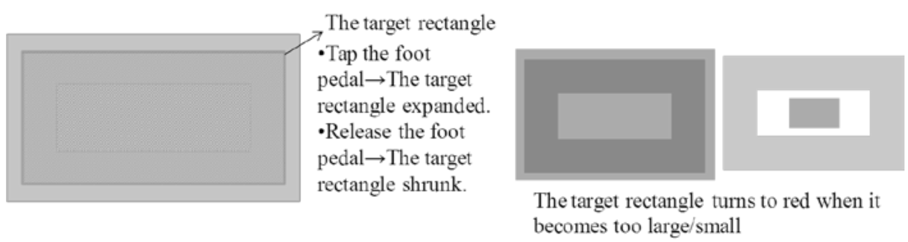

Figure 1. Pedal tracking task

The participants' goal was to keep the outer edge of the target rectangle inside the yellow area by controlling a foot pedal. To simulate adjust inter-vehicle distance controlling an acceleration pedal, the size (side length) of the target rectangle (D) was defined by the 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 equaled 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 fluctuation signal was generated from a mixture of four sine waves.

Secondary tasks (CE tasks)

We developed the following inhibition, shifting, and updating tasks in both visual and audio conditions. The secondary task was presented in the top left quadrant of the secondary display.

(1) Visual Inhibition (VI). We used the Stroop task from the screening test as a visual inhibition task.

(2) Audio Inhibition (AS). We used a modified auditory Stroop task based on previous research (Hamers et al., 1972; Morgan, A., 1989). Three different words ("High", "Day", "Low") were presented individually in two pitches (High pitch: 290Hz, Low pitch: 110 Hz) with semi-random word-pitch combinations (the numbers of each combination of word-pitch was balanced). The participant's task was to indicate the pitch by pressing a corresponding key (low = left arrow, high = right arrow).

(3) Visual Shifting (VS). A single digit was presented on a display with three single digit numbers underneath it. Participants were expected to apply one of the rules (-1, +0, +1) to the target number, and then choose the answer from the three options provided. Participants were instructed to find the expected rule as quickly as possible and to apply the same rule until it changed (ex., -1, -1, -1, -1,..., +0, +0, +0, +0,...). After eight consecutive correct responses, the program changed the rule.

(4) Audio Shifting (AS). The procedure in this task was equivalent to the VS task except that all the stimuli were presented in audio; A single digit number (1-8; the target number) was presented in a high-pitched voice (290Hz) followed by three single digit number (0-9) in low-pitch voice (110Hz) as options. Feedback to an incorrect response was given using a beep sound. The three option numbers corresponded to the left, down and right arrow keys, in that order.

(5) Visual Updating (VU). 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 when the third instance of each circle color was presented (e.g., after seeing the third blue circle, or the third yellow 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.

(6) Audio Updating (AU). The procedure in this task was equivalent to the VU task except that all the stimuli were presented in audio; instead of the colored circles, participants were presented with high-pitched tones (880Hz) and low-pitched tones (220Hz) for 500ms, with an inter-

stimulus interval of 2500ms. They were instructed to respond to the second occurrence of tones. This was the modified procedure (Miyake et al., 2000) of the Mental Counters task (Larson et al. 1988).

Apparatus

The main and CE task programs were run on the same computer (Hardware: Gigabyte Technology Co., Ltd./ X58A-UD3R, OS: Microsoft Windows XP Professional), and were shown on the main display (Acer 23"/58cm Wide LCD Monitor, S231HL) and secondary display (Dell E177FPf TFT, E177FPf) correspondingly. Participants' input was given with a foot pedal (Logitech/ Driving Force GT) for the primary tasks, and with a keyboard for the secondary tasks. Experimental equipment was set up as shown in Figure 2.

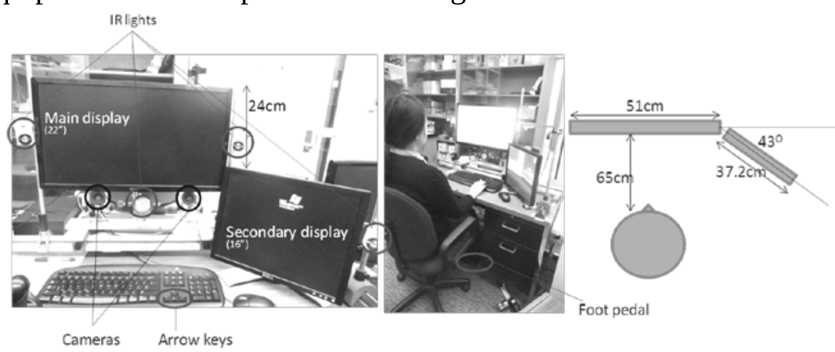

Figure 2. Experiment settings

Procedure

All experimental sessions were conducted at University of Toronto from January through March 2012. Participants participated in the experiment individually. The participants first performed the pedal tracking task as a single task. They then performed the pedal tracking task and CE tasks as dual tasks. The CE tasks consisted of the six CE function conditions (AI, VI, AS, VS, AU, and VU). The order of the CE task was varied among participants. Each participant was exposed to all 6 dual task conditions (one CE task at a time), with approximately two minutes' worth of trials per condition. Ordering of conditions was counterbalanced between participants. Participants were instructed to respond as quickly and accurately as they could, and to perform as well as they could on both of the tasks. Participants were paid for their participation and signed a consent form before participating, in accordance with a research protocol that was approved by the University of Toronto Ethics Review Board.

Results

Based on eye tracking data, we calculated the proportion of the time that participants viewed the main vs. the secondary task display (main display gaze rate). Due to missing data, eye gaze data for 22 of the participants was used in this analysis. Figure 3 shows the main display gaze rate (line) and pedal tracking task error rate (bars) across the six secondary task conditions. Error bars shown in this and following figures are standard errors. The main effect of modality on gaze rate to the main display was higher in the audio vs. visual secondary task conditions ($F[1, 21]=11.41$, $p<.005$), i.e., there was less visual distraction in the audio conditions. However, the VU condition showed a higher gaze rate on the main display (lower visual distraction) as compared to the other visual conditions. This may be because the VU task could be performed using peripheral vision, since the stimuli (colored circle of 8cm in diameter) were large enough, as was reported by some of the participants.

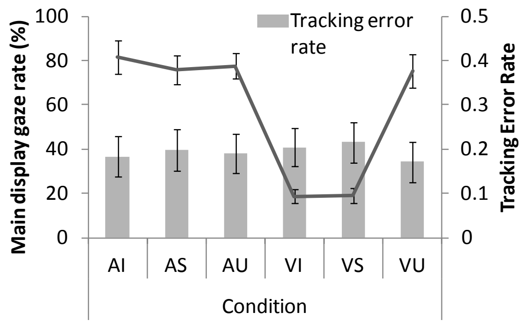

Figure 3. Main display gaze rate and the primary task performance

Analysis of covariance was run with the three CE function abilities (inhibition, shifting, updating) as covariates, the three CE loading tasks as one within subjects factor, and the modality of secondary task presentation (visual vs. auditory) as a second within subjects factor. There was a borderline significant three way interaction between shifting ability and the two other factors (CE loading tasks, modality) (F[1.63, 49]=2.72, p<.10), with degrees of freedom in the analysis adjusted using the Greenhouse-Geiser criterion to account for non-sphericity. After viewed the histogram of shifting ability (as measured by number of completed rules in the WCST), we defined high shifting ability as those people who completed seven or more rules (with low ability assigned for fewer than seven completed rules). We plotted the three way interaction between the high vs. low measure of shifting ability, CE loading tasks and modality. From visual inspection there seemed to be an interaction between shifting ability and modality for the inhibition secondary task, but only a shifting ability main effect for the updating and shifting secondary tasks. We then carried out two follow up analyses: a) analysis of the suspected two way interaction between shifting ability and modality for the inhibition secondary task; b) analysis of the three way interaction between shifting ability, modality and CE loading task (with updating and shifting only). As expected, there was a significant interaction between modality and shifting ability for the inhibition secondary task (F[1.32]=7.27, p<.05). As shown in Figure 4 (left), people with high shifting ability generally had a lower pedal tracking error rate in the presence of the inhibition secondary task. In addition, people with higher shifting ability were not affected by presentation modality of the secondary task, while people with lower shifting ability did better with auditory (vs. visual) presentation of the secondary task. In the second analysis (looking at the three way interaction, but with only the shifting and updating loading secondary tasks), the only significant effect (there were no significant interactions) was the main effect of shifting ability (F[1,31]=7.73, p<.01). Figure 4 (right) shows the corresponding plot for the data pooled across the shifting and updating secondary tasks. Primary Pedal Tracking (PPT) Performance was much better for people with high shifting ability.

In order to demonstrate that the lower error rate in visual conditions for people with high shifting ability was due to visual switching between primary and secondary tasks, we plotted relevant eye gaze data (Figure 5). As expected, for the inhibition and updating tasks there were significantly more switches in gaze between the monitors for people with high shifting ability. For the shifting secondary task there was a tendency for high shifting ability people to have more shifts in gaze, but this difference was not statistically significant.

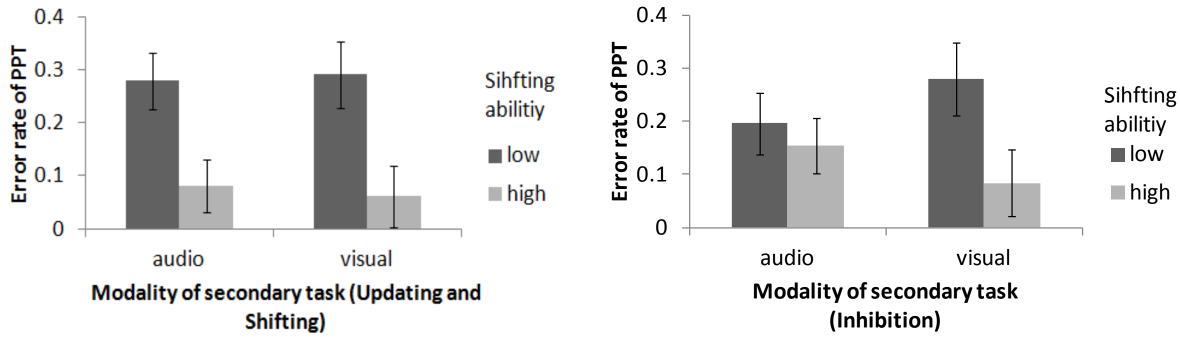

Figure 4. PPT error rate by secondary task modality and shifting ability (left: for Inhibition task only, right: for Updating and Shifting task only)

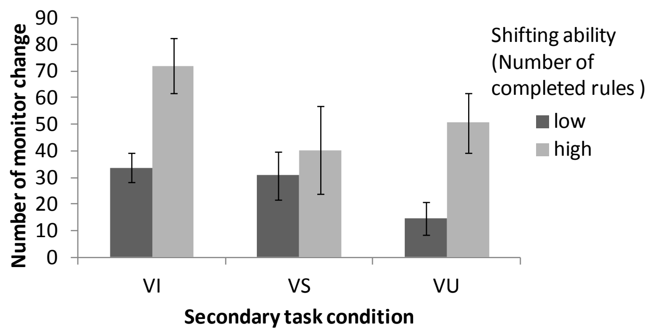

Figure 5. Number of switches in gaze between monitors by shifting ability and secondary task (visual only) condition

DISCUSSION AND CONCLUSION

People with high shifting ability compensated for the effects of visual distraction by switching visual attention more frequently between primary and secondary tasks. This greater visual switching was most pronounced in the inhibition and updating secondary conditions. The reduced switching advantage for high shifting participants in the shifting loading secondary condition likely occurred because the secondary task was consuming CE shifting resources, reducing availability of shifting resources for switching attention between tasks.

Overall, we found that shifting ability was the most important of the cognitive abilities relating to CE function, moderating the relationship between modality and secondary task loading when pedal-tracking was the primary task. People with higher shifting ability generally performed better on the pedal-tracking task (with fewer errors) across all modalities and CE loading secondary tasks. That general pattern of superiority for those with high shifting ability was also true with tasks that loaded on the shifting, and updating, CE functions. However, for the inhibition loading secondary task we observed an interaction between shifting ability and modality such that, for people with high shifting ability, visual presentation led to better performance (lower pedal tracking errors) whereas for people with low shifting ability auditory presentation led to better performance.

Further research is needed to confirm these results, particularly in driving simulators or vehicles. However, one implication of this work is that type of secondary display should depend on the shifting ability. Low shifting ability drivers should benefit from auditory display of secondary tasks, while high shifting ability drivers should perform better with visual display of those tasks. It remains to be seen if, given the choice, will people choose a mode of presentation (visual or auditory) for a secondary task that correctly matches their level of shifting ability.

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