Reasons to Switch: the Effects of Priority and Information Presentation on Dual-Task Interleaving Strategies

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ABSTRACT

When people engage in two or more concurrent tasks, they often have to interleave attention between them. For example, drivers using a navigation device will likely make frequent, short glances away from the road to read directions. To explore the strategy space of people's interleaving behaviour, an empirical study investigated how information presentation interacts with performance objectives. Participants either prioritised safe driving or fast performance on a navigating reading and entry task. The navigating task varied in terms of the external representation used for presenting information to drivers and the presence or absence of an external cue to support drivers resume the task following a glance to the road. The results demonstrate that giving explicit instructions to prioritise one task leads to a classic speed-accuracy trade-off between driving and navigating task performance, and that information presentation can further influence dual-task interleaving behaviour. These findings highlight the need for designers to consider the motivations of users, as well as limitations in human information processing, especially when people are accessing information in rapid bursts.

LIST OF TABLES AND FIGURES

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

As technology becomes increasingly ubiquitous, multitasking becomes more of a facet of modern life. The typical morning of a technophile could include reading news and blogs while making breakfast, checking e-mail while commuting to work, and juggling a multitude of tasks of varying levels of urgency once the work day begins. While mobile devices enable people to remain connected to information, they also carry the potential to distract. One familiar example is the effect of mobile phones on driving performance (e.g. Alm & Nilsson, 1994; Brumby, Salvucci, and Howes, 2007, 2009; Salvucci, 2001, 2005). As research has identified the risks involved when using mobile devices while driving, the next steps are to develop a deeper understanding of the processes involved when people interleave attention between these tasks.

Consider the simple scenario of someone dialing an unfamiliar phone number printed on a business card (e.g. "xxx-xxx-xxxx"). How do they interleave the task of reading the phone number on the card and dialing the number into a phone? One possibility is that they break the task of dialing the phone number into subtasks, or chunks, for example memorising the first three digits, dialing them, then memorising the next three digits, dialing them, and so on. Another possibility is that they memorise as many digits as they can maintain in working memory, for example memorising the first five digits (if that's their capacity), dialing them, them memorising and dialing the next five digits. If the person has a poor memory, they may not be able to store more than one or two digits at a time and as a result will have to look back and forth frequently between the looking at the phone number and dialing.

Now suppose that this person is dialing the phone number while driving a car. If the person is a safe driver, they may assign less priority on dialing the phone number than someone who isn't a safe driver. In this safety-critical scenario, the driver must now consider the risks of shifting visual attention away from task of driving to the task of reading the phone number. A safe driver may determine that they can safely look away from the road for 1 second at a time, and in that second they will read as many digits as they can, look back to the road, then dial the digits, and repeat this process until the task is completed. A risky driver, on the other hand, may spend 10 seconds dialing the phone number in one continuous look.

Interleaving behaviour may also be determined by how the phone number is presented—if it is printed in an unreadable font or a foreign format, for example, more glances may be required to complete the dialing task. So far in this scenario, four possible factors have been identified which could determine interleaving behaviour: 1) subtask boundaries 2) memory capacity 3) the priority assigned to tasks and 4) perceptual encoding.

This dissertation is interested in how performance objectives (which are defined by task priority) and information presentation influence dual-task interleaving strategies, and how information displays can be better designed to support dual-task interleaving. The structure of the dissertation is as follows: Chapter 2 reviews relevant literature to dual-task interleaving and designing for multitasking environments. Although studies have shown that people use subtask boundaries as a cue to interleave (e.g. Salvucci, 2005), people may be motivated to interleave before a subtask boundary in the interest of safety (Janssen & Brumby, 2009). Interleaving behaviour can be further influenced by performance objectives (Brumby et al., 2007, 2009; Eng et al., 2006; Schumacher, et al., 2001; Wickens & Seidler, 1997). Taken altogether these findings suggest that task interleaving strategy is driven by a combination of factors.

Chapters 3 and 4 present a series of two experiments in which participants are asked to complete a lanekeeping task in a driving simulator while completing a navigating task that involves reading and entering a list of directions. Participants are either instructed to prioritise the driving-task or the navigating-task. In manipulating priority, it was predicted that a speed-accuracy trade-off would occur, such that focusing on one task will lead to a performance decrement in the other task.

The experiments also investigated low-level strategies when interacting with the information display used in the navigating task. Information presentation was varied by manipulating the presence of an external cue and the external representation of information. Interruption research has demonstrated that external cues aid task resumption (Ratwani & Trafton, 2006; Trafton, Altmann & Brock, 2005), so it was predicted that external cues would improve task performance. Memory research has shown that people prefer to encode information verbally in serial recall tasks (Brandimonte & Gerbino, 1993; Brandimonte, Hitch, & Bishop, 1992), so it was predicted that text representations would perform better than a graphic arrow representations.

Chapter 5 interprets the findings with reference and draws out implications for interleaving strategies. Limitations and future directions will also be discussed, as well as implications for the design of displays in multitasking environments.

CHAPTER 2. LITERATURE REVIEW

The purpose of this literature review is to introduce factors that could determine dual-task interleaving strategy. This chapter will first review how people can adapt strategies to their task environments and how task structure can influence dual-task interleaving strategy. It will then be argued that task structure alone cannot explain dual-task interleaving strategy, and examples of other explanatory factors such as performance objectives and information presentation will be presented. The rest of the chapter discusses how information presentation can influence dual-task interleaving behaviour, focusing specifically on how external cues and external representations could alleviate the cognitive demands of display-based tasks. This chapter will then conclude with a summary of the relevant literature, focusing on questions that these experiments aim to address.

2.1. Strategies and interactive behaviour

By manipulating task focus, these experiments aim to demonstrate that people can flexibly adapt dual-task interleaving strategy to meet explicitly set performance objectives. Previous research in HCI has demonstrated that people adapt interactive behaviour to the task environment (Gray, Sims, Fu & Schoelles, 2006; O'Hara & Payne, 1998). Interactive behaviour is how people achieve internal mental goals through an external task environment, and as a result interactive strategies are subject to design of the task environment and limitations of human cognition (Gray, Neth, and Schoelles, 2006). For example, problem-solving studies have shown that when the cost of interaction with an interface is increased, users switch from interaction-intensive strategies to memory-intensive strategies (Gray, Sims, Fu & Schoelles, 2006; O'Hara & Payne, 1998).

Different hypotheses have proposed how users estimate cost to select low-level strategies. One hypothesis proposes that users select strategies to minimise load on working memory (Ballard, Hayhoe, Pook, and Rao, 1997), while the soft constraints hypothesis (Gray, Sims, Fu & Schoelles, 2006) proposes that users select strategies based on temporal cost-benefit tradeoffs. Gray & Boehm-Davis (2000) suggested that people are highly sensitive to the temporal cost of interactions on the order of milliseconds. These findings suggest that interactive strategies are driven by both the task environment and a valuation of cost by the user.

In real-world complex tasks, strategy selection is not motivated solely towards minimising memory load or minimising task time— it depends on the goal of the task, which may require consideration of multiple performance objectives. Eng et al. (2006) argue that people select strategies based on their specific performance objectives. One example of particular interest is multitasking, in which multiple tasks have to be performed, each with different performance objectives. Constraints in human cognition can limit the extent to which multiple tasks are performed in parallel (e.g. Meyer & Kieras, 1997), and performance objectives will determine how these tasks are prioritised.

Studies have explored how people select strategies when given explicitly defined task priorities (Brumby et al., 2007; Schumacher et al., 2001; Wickens & Seidler, 1997). In a driving-simulator experiment, Brumby et al. (2007) had participants dial a memorised phone number on a mobile phone while driving. Participants were encouraged to either focus on minimising lateral deviation or on minimising dialing time. When participants focused on driving they deviated less but had longer dialing times, and when participants focused on dialing they had faster dialing times but more lane deviation. This suggests that high-level metacognitive factors such as explicit priority instructions can influence strategy selection. This study also found that when dialing a phone number with a US format (i.e., xxx-xxx-xxxx), participants interleaved between phone number chunks. This supports previous research that has found that in tasks with a hierarchical structure, people choose to interleave at subtask boundaries (Salvucci, 2005).

In a follow-up study, Janssen and Brumby (2009) used a phone number with a different chunk structure (i.e., xxxxx-xxxxxx) and found that participants explicitly represented task structure by interleaving before chunk boundaries. This suggests that subtask boundaries are only one factor people use to determine interleaving. Interleaving behaviour could also be memory driven—participants may have decided to break the large represented chunks into smaller chunks because they are easier to maintain in working memory.

Another possibility is that interleaving behaviour is determined by an internally-driven pressure to switch to a time-critical task. Kushleyeva et al. (2005) propose that in real-life scenarios that are time-critical, people reason about the temporal aspects of each task, and that task switching can be driven by pressure which builds up as one spends more time on a single task. This explanation of dual-task interleaving lends itself well to a driving situation—people are aware that they can only allocate attention away from driving in short bursts if they want to minimise risk of accidents.

Although dual-task interleaving strategy is influenced by the task environment, the research reviewed suggests that other factors, particularly internal cognitive constraints, can also determine dual-task interleaving strategy. If cognitive constraints influence dual-task interleaving strategy, task interfaces should address these constraints by alleviating memory and perceptual demands. The following two sections discuss how display-based tasks that are visually and memory-intensive can alleviate these demands, and in turn influence dual-task interleaving strategy.

2.2. External cues and task switching

The work discussed in the previous section has illustrated how varied strategic behaviour can be, with a specific emphasis on multitasking settings. In this section we will further illustrate how external cues can influence behaviour. We will cast these examples within the memory-for-goals theory.

Memory-for-goals theory (Altmann and Trafton, 2002) explains how goals can be resumed after being suspended. The first assumption of memory-for-goals theory is that when a goal is suspended due to a task switch, the memory of the suspended goal weakens, and the weaker the memory is the more difficult it will be to resume. The second assumption is that these memories can be strengthened by rehearsing the suspended goal. The third assumption is that cues can prime the suspended goal, boosting its activation.

Memory-for-goals theory considers external cues helpful for task resumption, and several studies have investigated the effects of external cues in interruption studies (e.g. Czerwinski et al., 2000; Cutrell et al., 2001; Ratwani and Trafton, 2006; Trafton et al., 2005). Czerwinski et al. (2000) were interested in whether subtle external cues can assist resumption of a visual search task where participants navigated through a list using a cursor keys. Before participants searched for an item they were either given either the exact search target or a gist description. Importantly, in one condition the cursor's selection was outlined. Their results were inconclusive in regards to cues—cues only improved search time when being given the search target, but not the gist. In a follow-up study, Cutrell et al. (2001) used a more salient cue (a blue highlight), but again found no main effect of marker presence. These findings suggest that external cues were not effective in improving task performance.

Trafton et al. (2005) provide two (non-exclusive) alternative explanations of why these studies found no main effect of cue. The first alternative is that they used a large-scale measure (overall trial time) which is prone to variability, and the variability of trial time may have overshadowed any effect of disruption. The second alternative is that cue position in these studies was determined by pressing cursor keys, and that visual scanning rate may have been faster than the rate of pressing the cursor. If participants were visually scanning ahead of the cue, then the cue may have been of minimal use for task resumption. In summary, the inconclusive results of Czerwinski et al. (2000) and Cutrell et al. (2001) may have been due to the experiment design.

Trafton et al. (2005) investigated how external cues facilitated task switching by using a resource allocation task which required participants to use a standard point-and-click operator interface. They found that if salient goal-relevant cues were used to remind participants of their place in the procedure, resumption time was reduced. In contrast to the studies of Czerwinski et al. (2000) and Cutrell et al. (2001), which relied on large-scale measures, Trafton et al. (2005) analysed low-level actions by recording keystroke and mouse-click data to measure resumption lag and calculate disruption. These findings suggest that external cues are indeed helpful for task resumption and that low-level behavioural data may be particularly useful for demonstrating these effects.

Although the study by Trafton et al. (2005) provides evidence that external cues can help task resumption, it was still unclear what the perceptual mechanisms are behind task resumption. Ratwani and Trafton (2006) explored these perceptual mechanisms by collecting eye-tracking data during a spreadsheet task. This task involved reviewing and copying a column of numbers while being interrupted by instant messages. The eye-tracking data from this study suggest that participants use both subtle external cues and a spatial heuristic to resume the task. External cues in this study allowed participants to infer the step to resume, while spatial heuristics helped participants remember the general area where they left off. These findings further support that external cues help task resumption.

The Ratwani and Trafton (2006) study looked at one type of subtle external cue that was present through all conditions, and although their results suggest that people use both external cues and spatial heuristic strategies, it is still unclear whether the presence of an external cue determines what resumption strategies people are more likely to adopt. For example, if an external cue is not present, people may rely more on spatial heuristic or retrace strategies. On the other hand, if an external cue is present and salient (such as in Trafton, 2005), this may obviate the need for spatial heuristic and retrace strategies.

In these interruption studies, the focus has been on resumption of the primary task, but in real-world scenarios it is often the case that both primary and secondary tasks require resumption, especially when the secondary task takes more than 1-2 seconds to complete and requires repeated task interleaving (Brumby et al., 2007; Salvucci, 2005). In this case, it is also important to understand how secondary tasks are resumed following a task switch. Furthermore, research has suggested that information can be perceived differently depending on whether it is on a focal and peripheral display (Tessendorf et al., 2002), which suggests that the mechanisms for task resumption could differ between primary and secondary displays.

The current experiments use a dual-task paradigm in which repeated interleaving is a necessary strategy—which means that both primary and secondary tasks require resumption. The presence of a goal-relevant external cue is manipulated, and it is expected that the cue will reduce resumption lag, which will lead to participants spending less time on the secondary task.

2.3. Representation effects

The previous section illustrated how external cues can improve task performance by reducing resumption lag, but in an information-heavy task it is also important that task-relevant information is represented in a way that is easy to understand and remember. The current experiments require participants to process visual information quickly for the secondary task, and the external representation used to display information could also influence behaviour. The external representation used was manipulated, in that information relevant to the secondary task was either rendered as an arrow list or text list. This section discusses how external representations can influence task performance, and how the effectiveness of an external representation is dependent on the nature of the task.

Zhang and Norman (1994) propose that different external representations can influence how people perceive a task, even when they represent the same abstract entities. An example they use to explain this “representation effect” is the task of calculating Roman and Arabic numerals. When multiplying, for example, Arabic numerals (e.g. 73 x 27) are easier to work with than Roman numerals (e.g. LXXIII x XXVII), even though these external representations convey the same meaning.

Representation effects have also been found in studies comparing the effectiveness of pictorial and word representations (Ainsworth and Loizou, 2003; Bauer and Johnson-Laird, 1993; Goolkasian, 1996; Larkin & Simon, 1987). However, as argued by Scaife and Rogers (1996), the effectiveness of an external representation is dependent on many factors, such as user’s familiarity with the representation, the knowledge domain, and the nature of the task for which the representations are being used. As a result, conclusions about the superiority of an external representation for a specific task can not necessarily be generalised to other tasks.

One applied domain where representation effects should be considered is the design of navigation devices. When designing navigation routes, selecting appropriate external representations could improve intelligibility, and lead to better navigation speed and accuracy. In a virtual navigation study, Chewar and McCrickard (2002) compared six different route representations (five of these visual representations are shown in Figure 2.1, the sixth was auditory). When comparing the mean trial time for each condition to the mean trial time for all six conditions, they found that the graphic representation (a pointing arrow) and audio command conditions had faster trial times than the overall mean. However, text and text lists also performed relatively well, and the data are inconclusive as to whether graphic and audio were significantly faster than the two text conditions.

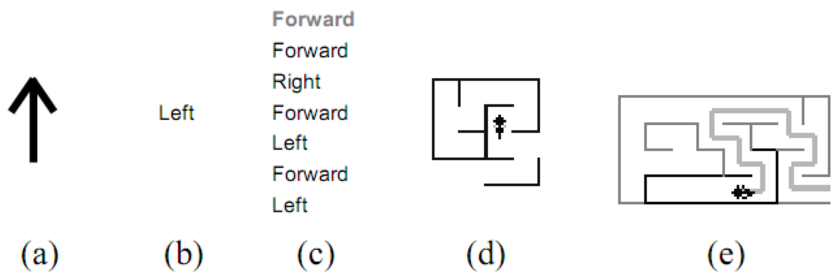

Figure 2.1. Visual representations from the Chewar and McCrickard (2002) study: (a) graphic, (b) text, (c) text list, (d) partial map, (e) full map with solution path.

Visual route descriptions in this study were easy accessible on the same screen as the maze navigation task. With the exception of heads-up displays, route information used while driving is usually not as readily available and will require an access cost such as a glance or a head-turn away from the road. Simple alterations in the interaction style with the interface, such as requiring a head movement instead of an eye-movement, can have drastic effects on the selected strategy, style of interaction and task performance (e.g. Ballard et al., 1995, 1997). Particularly, as interaction is made more costly, people reduce the amount of interaction with the interface, and increasingly rely on memory for future actions (Ballard et al., 1995, 1997; Fu & Gray, 2006; Gray et al, 2006). Given that navigating while driving comes at a large interaction cost, we expect drivers in such a scenario to adopt memory-intensive strategies. This will differ from the simple maze navigation situation of Chewar & McCrickard (2002), which has a lower information access cost and thus enforces more interaction-intensive strategies.

The current study compares graphic (arrow) list and text route representations for a task that is more memory-intensive than the Chewar & McCrickard (2002) study. Studies in working memory have suggested that people, when asked to memorise and recall serial information, prefer to encode information in verbal code, even when the information is presented in a non-verbal format (Brandimonte & Gerbino, 1993; Brandimonte et al., 1992). It is thus predicted that text route representations will perform better than arrow route representations for the secondary task of these experiments, in that text lists will be faster to encode and memorise.

2.4. Summary

The first section illustrated that although task structure can to some degree determine dual-task interleaving strategy, other factors such as performance objectives and cognitive constraints should also be considered. To address limitations in memory and perceptual processing, the second and third sections argued that information presentation could further influence interleaving behaviour. Specifically, external cues can speed up resumption of a task and reduce demands on working memory and appropriate external representations can lead to more efficient and reliable encoding of task-relevant information.

CHAPTER 3. EXPERIMENT 1

To investigate the influence of performance objectives and information presentation on dual-task interleaving strategy, a dual-task paradigm was devised in which participants completed a visually and memory-intensive navigating task while driving a simulated vehicle. The driving task was a lanekeeping task that required participants to remain in the centre lane of a three-lane highway. The navigating task required participants to read a list of route instructions from a navigator display and manually enter them into the simulator's steering wheel controls. In addition to collecting global measures of driving-task and navigating-task performance, more specific event-based measures such as the frequency and duration of visits to the navigator display were also collected to develop a more complete view of dual-task interleaving patterns (see Table 3.2.1).

To understand the effects of performance objectives on dual-task interleaving strategy, task focus was varied between participants, so participants either focused on the driving-task or the navigating-task. In a similar method as Brumby et al. (2007), the assigned task focus was instructed explicitly before the dual-task trials and frequently reinforced through feedback which reflected the assigned task focus. Limits on cognitive resources should lead to a speed-accuracy trade-off, such that participants that prioritise the driving task will have better overall driving performance, but worse performance in the navigating task, and participants that prioritise the navigating task will have better overall navigating performance, but worse performance in the driving task. In addition, different interleaving patterns should emerge between the two groups, such that participants in the driving-focus condition will have more frequent visits of shorter duration, while participants in the navigating-focus condition will have less frequent visits of longer duration.

To understand the effects of information presentation on dual-task interleaving strategy, the information display used in the navigating task was varied in terms of memory and perceptual demand. The presence of a salient and goal-relevant external cue was manipulated; the purpose of the cue was to remind participants of their current place in the navigating task, thereby lowering demands on working memory. Based on memory-for-goals theory (Altmann & Trafton, 2002), which proposes that cues from the task environment can help strengthen memory of suspended goals, it was predicted that the cue in this experiment would assist resumption of the secondary task. When an external cue is present, visits to the secondary display will be shorter and less time will be spent visiting the navigator display.

The external representations used in the navigating task were also manipulated, such that route descriptions were either represented as text or arrow lists. Working memory research suggests that in serial recall tasks, people prefer to encode information in verbal code, even when presented in a non-verbal format (Brandimonte & Gerbino, 1993; Brandimonte et al., 1992). If participants prefer to encode and rehearse route directions in a verbal code, route descriptions that are represented in a text format should require less time to encode per item than a graphic format, and in turn lead to better secondary task performance and less disruption to the primary task.

3.1. Method

Participants.

Participants were eight students (four female) at University College London, aged between 22- and 37-years (*M* = 29.75 years, *SD* = 6.09 years). All participants had a valid driver's license and at least two years of driving experience (*M* = 12.63 years, *SD* = 6.44 years). Participants were unpaid volunteers that were recruited through flyers and electronic mailing lists.

Design.

The experiment followed a 2x2x2 mixed factorial design with the independent variable of task focus (driving-focus; navigating-focus) between-subjects and the independent variables of route representation (graphic; text) and cue presence (non-highlighted; highlighted) within-subjects. Task focus was assigned to participants in alternation and balanced across gender. The order of route representation and cue presence conditions were counter-balanced across participants to minimise order effects.

The dependent variables collected in this experiment were root mean square error (RMSE) lateral deviation, trial time, number of visits per trial, average visit duration, average drift during visits, average post-visit duration, average correction during post-visits, number of actions per visit, encoding rate, and total visit time (see Table 3.2.1 for definitions).

To investigate how performance objectives affect dual-task interleaving strategies, participants were either given instructions to prioritise the driving-task or instructions to prioritise the navigating-task. Instructions given to participants before the dual-task blocks which informed them of their assigned task focus (see Appendix A). The scores used to provide feedback to participants during dual-task blocks were determined by the assigned task focus (RMSE lateral deviation for the driving-focus group, and trial time for the navigating-focus group).

To investigate how information design could affect dual-task interleaving strategies, the display used for the secondary task was manipulated in terms of cue presence and external representation.

Materials.

A schematic of the experiment set-up is shown in Figure 3.1.1. For the driving-task, a 30-inch monitor was used to display the driving simulator environment. For the navigating-task, a 17-inch monitor positioned to the left of the participant displayed the route descriptions. Participants used a Logitech G25 Racing Wheel to steer for the driving-task. For the navigating-task, a standard Macintosh keyboard positioned in front of the navigator display was used by participants to request access to route instructions, and paddle controls under the steering wheel were used by participants to input route directions.

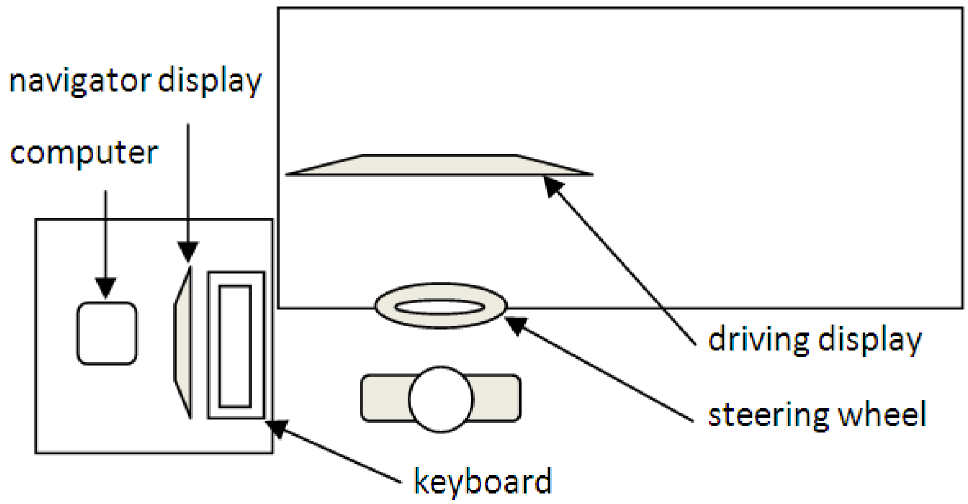

Figure 3.1.1. The physical set-up of the driving and navigating tasks (not drawn to scale).

Driving Task.

The simulated driving environment consisted of a three-lane highway driving environment with safety cones placed on both sides of the centre lane to encourage drivers to stay within boundaries. The objective of the driving task was to keep the vehicle in the centre of the centre lane. Participants followed another vehicle in the simulator environment at a constant speed of 55 mph. The constant-speed paradigm was used so that participants would not have the opportunity to slow down in response to distraction, and by not taking the factor of speed into account driving performance analysis will be simplified to the measure of lateral deviation from the lane centre.

Navigating Task.

The objective of the navigating task was to read the route instructions and enter the directions using two paddle controls under the steering wheel. To view route instructions, participants needed to press and hold down the keyboard spacebar. Participants were required to release the spacebar (which masked the route instructions) before entering directions, which made it necessary to rely on memory to enter the directions. Participants were free to interleave between viewing the route instructions and entering directions as many times as they needed to.

The route used in the navigating task consisted of a list of ten instructions. The instructions were randomly determined at the beginning of each trial, with the constraints that (1) five left and five right directions were included (2) not more then three consecutive repeating instructions were present. These instructions were displayed as numbered lists rendered in black on a white background (see Figure 3.1.2).

Depending on the route representation condition, instructions were either rendered as arrows (left or right pointing) or as text ("Left" or "Right"). Depending on the cue presence condition, the currently active direction (i.e., the first one that needed to be entered) was either marked with a yellow highlight or not marked. In the highlighted condition, the position of the highlight was updated as participants entered directions correctly.

In the case of an input error, the participant was notified as soon as the error was made, and the experiment would proceed to the next trial. Participants were discouraged from making errors in two ways: when feedback was trial time, a score of 60 seconds was given whenever an error occurred, and participants were required to complete an additional trial for each trial where an error occurred.

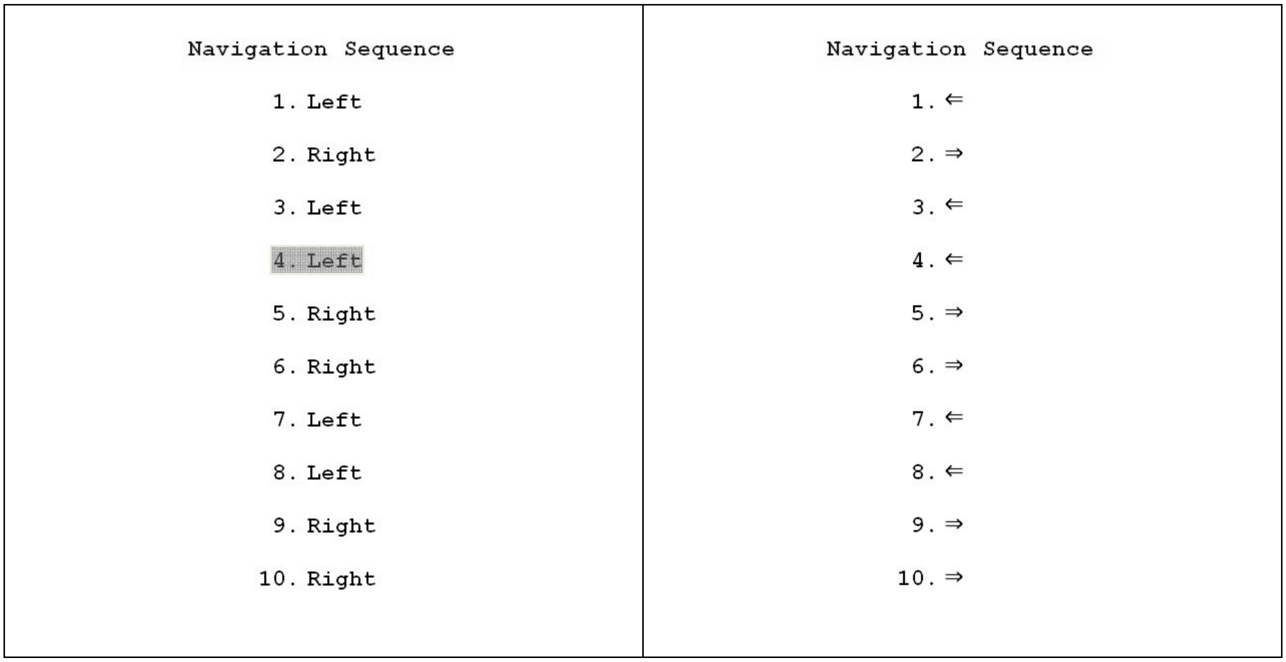

Figure 3.1.2. Left: A text list with highlight-cue. Right: An arrow list with no cue.

Procedure.

The experiment consisted of two practice blocks and five experiment blocks. The participants first completed a single-task practice block for driving, followed by a single-task practice block for navigating. Then participants completed four dual-task blocks, with a block of single-task driving trials (to measure baseline driving performance) between the second and the third dual-task block. Following each dual-task block the participants were given a short break (30 seconds after the first and third dual-task blocks, 60 seconds after the second dual-task block).

Single-task practice blocks.

The participants were not informed of their assigned task focus at this stage and practice block instructions were the same for both focus groups (see Appendix A). For the driving practice block, participants were told to keep as close to the centre of the lane as possible and that feedback would be given at the end of each trial in the form of a lateral deviation score. The driving practice block consisted of five 30-second trials.

For the navigating practice block, participants were told to enter the route instructions into the paddle controls as quickly as possible, and feedback in the form of trial time was given at the end of each trial. The navigating practice block consisted of eight trials (two trials in each condition), and cues were given to inform participants of the condition of the following trials (e.g. "Text List, Highlight will NOT be used"). If an entry error was made, participants were notified as soon as the error was made and the experiment would proceed with the next trial.

Dual task blocks.

After the single-task practice blocks, participants were given instructions for the dual-task section of the experiment and informed of their assigned task focus (see Appendix A).

If the participant made an entry error, an error message box would be displayed as soon as the error was made. A dual-task block would be completed when the participant completed ten successful trials for that block, or once fifteen trials (of which some unsuccessful) had been completed, whichever came first.

Before each dual-task block, a cue was shown on the driving display indicating the condition of the upcoming block. A dual-task block began with the vehicle accelerating while a message box on the driving display instructed participants to wait and stay in the centre. Once the vehicle reached full-speed, the message box changed to indicate the start of the trial. In order to start the navigating task, the vehicle needed to be in the centre lane (within 0.75m of the centre). If the participant was not centred and attempted to start the navigating task, a message would appear on the navigator display instructing them to centre their car before starting the navigating task.

Once the navigating task was completed, participants centred their vehicle (within 0.3m of the centre) to complete the trial. The participants were given 60 seconds in each trial to complete entry of the route instructions and centre the vehicle—if this was not completed in 60 seconds a message box appeared on the driving display notifying the participant that the time limit has been reached and the next trial would begin. After completing the trial, a message box on the driving display showed the participants a feedback score for five seconds before starting the next trial. The participant would continue driving at full speed between trials, with the exception that at the end of every fifth trial the participant would be given an average score for the previous five trials and the driving simulator would restart.

After the second dual-task block, participants completed a block of five single-task driving trials. The purpose of this block was to provide baseline driving performance data. This block had the same structure as the driving practice block.

3.2. Results

From the raw data error trials were excluded, as global measures (e.g. trial time, RMSE lateral deviation) needed to be compared across completed trials. Of a total of 364 trials, 45 trials (12.36%) were excluded due to participant error (i.e., they pressed the wrong paddle which did not correspond with the route instructions), leaving 319 successful trials for further analysis. The dependent measures of interest were lateral deviation from the centre of the lane, trial time, and eight other measures described in Table 3.2.1. Unless otherwise stated, a 2x2x2 mixed factorial ANOVA with variables of task focus (driving; navigating), cue presence (non-highlighted; highlighted), and route representation (arrows; text) was used for statistical analyses. Task focus was analysed as a between subjects variable, while cue presence and route representation were analysed as within-subject variables. An alpha-level of 0.05 was used throughout.

Table 3.2.1. Definitions of dependent variables.

Dependent variable	Definition
Number of visits per trial	The mean number of times the navigator display was visited, based on the count of distinct spacebar presses.
Average visit duration	The mean duration of visits to the navigator display, calculated as the time between spacebar press and release.
Average drift during visits	The mean relative change in lateral position during visits to the navigator display.
Average post-visit duration	The mean duration of post-visit events, calculated as the time between spacebar release and the next visit (or trial end).
Average correction during post-visit	The mean relative change in lateral position during post-visit events.
Number of actions per visit	The mean number of route directions entered post-visit, based on paddle control input data.
Encoding rate	The mean number of number of actions per visit divided by average visit duration.
Total visit time	Total time spent looking at the navigator display per trial, calculated as mean number of visits per trial x average visit duration.

Driving performance.

The dependent measure used to analyse overall driving performance was the root mean square error (RMSE) lateral deviation over the trial. The first analysis compared RMSE between the dual-task trials (compressed across display conditions) and the single-task baseline driving trials. The second analysis compared RMSE between different conditions for successful dual-task trials. The simulator logged the lateral distance of the vehicle from the lane centre at a rate of 200 Hz. The RMSE of these cumulative lateral deviation samples was then calculated over course of the trial (the time between the trial start message and the participant positioning the car in lane centre following route entry completion).

Figure 3.2.1 shows the RMSE lateral deviation of the two task-focus groups in the single-task driving block and the dual-task blocks. Participants had less lateral movement during the single-task driving block (*M* = 0.29m, *SD* = 0.11m) than the dual-task blocks (*M* = 0.55m, *SD* = 0.23m). For dual-task blocks, participants in the driving-focus group had less lateral movement (*M* = 0.4m, *SD* = 0.13m) than participants in the navigating-focus group (*M* = 0.73m, *SD* = 0.30m).

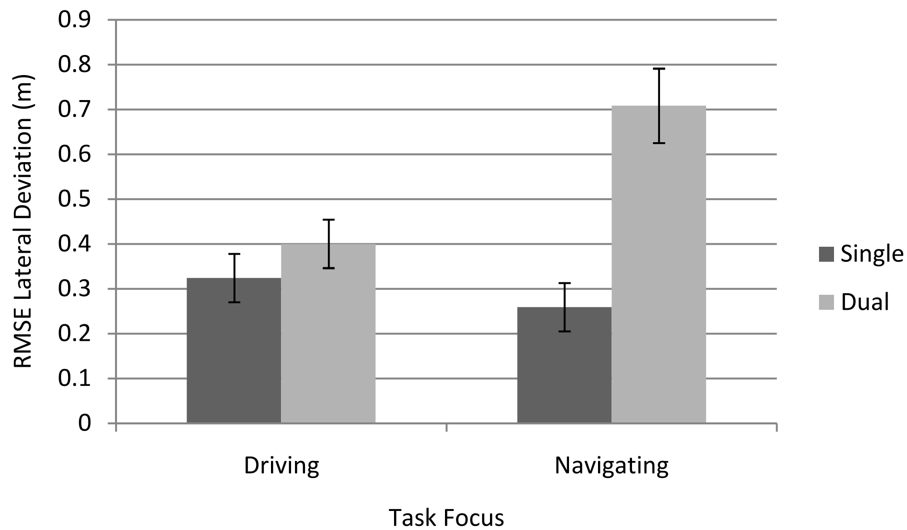

Figure 3.2.1. RMSE lateral deviation for single-task and dual-task trials for both task-focus groups. Error bars are standard error of mean.

A 2x2 mixed factorial ANOVA with the variable of task focus (driving-focus; navigating-focus) analysed between-subjects and the variable of experiment part (single-task; dual-task) analysed within-subjects. A statistically significant main effect of experiment part was found, $F(1, 6) = 35.98$, $p = 0.001$. There was also a statistically significant main effect of task focus, $F(1, 6) = 8.25$, $p = 0.03$. Furthermore, there was a significant interaction between experiment part and focus, $F(1, 6) = 18.6$, $p = 0.005$.

For dual-task blocks, there were no significant main effects for cue presence ($p = 0.53$) or route representation ($p = 0.34$).

Navigating task performance.

The dependent measure used to analyse overall navigating task performance was trial time, which was the time between the trial start message and the participant positioning the car in lane centre following route entry completion. Participants in the navigating-focus condition had faster trial times ($M = 16.7$s, $SD = 4.97$s) than participants in the driving-focus condition ($M = 38.02$s, $SD = 8.74$s), and this main effect of task focus was statistically significant, $F(1, 6) = 0.04$. For the cue presence manipulation, participants had faster trial times in the highlighted condition ($M = 20.40$s, $SD = 9.14$s) than in the non-highlighted condition ($M = 24.32$s, $SD = 8.81$s), and this main effect of cue presence was statistically significant, $F(1, 6) = 6.46$, $p = 0.04$. For the route representation manipulation, participants had faster trial times in the text condition ($M = 20.48$s, $SD = 8.27$s) than in the arrow condition ($M = 24.24$s, $SD = 9.67$s), and this main effect of route representation was also statistically significant, $F(1, 6) = 12.11$, $p = 0.01$.

Event-based measures.

Six event-based measures of interest were used to consider task interleaving during dual-task trials: number of visits per trial, number of actions per visit, average visit duration, average drift during visits, average post-visit duration, and average correction during post-visits. These measures were based on two types of trial events: visits were when the participant pressed the keyboard spacebar to view the route instructions on the navigator display, and post-visits were when the participant released the spacebar and returned focus to the driving simulator (see Figure 4.1).

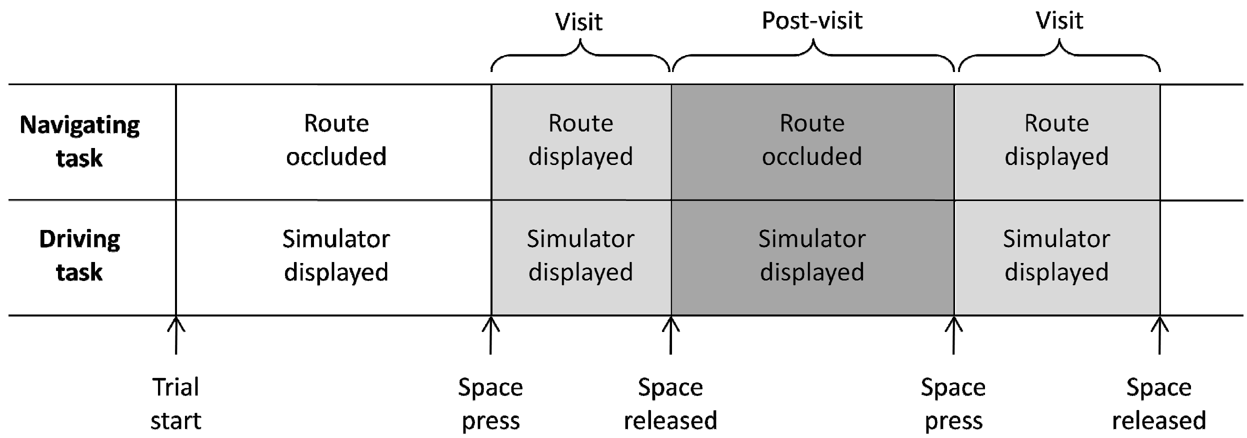

Figure 3.2.2. Visit and post-visit trial events for first experiment.

Visit measures.

Number of visits per trial was calculated as the mean number of distinct spacebar presses over the course of a trial. Participants in the navigating-focus condition made less visits per trial (M = 2.88, SD = 0.72) than participants in the driving-focus condition (M = 4.62, SD = 1.37), and this main effect of task focus was statistically significant, $F(1, 6) = 9.06$, $p = 0.02$. For the route representation manipulation, participants made less visits in the text condition (M = 3.34, SD = 1.19) than in the arrow condition (M = 4.16, SD = 1.5), and this main effect of route representation was statistically significant, $F(1, 6) = 9.59$, $p = 0.02$. There was no significant main effect for cue presence, $p = 0.72$.

Number of actions per visit was calculated by counting the number of route directions entered into the paddle controls following each visit to the navigator display. Participants in the navigating-focus condition entered more actions per visit ($M = 3.38$, $SD = 1.12$) than participants in the driving-focus condition ($M = 2.16$, $SD = 0.79$), and this main effect of task focus was significant, $F(1, 6) = 12.96$, $p = 0.01$. Participants entered more actions per visit in the text condition ($M = 3.15$, $SD = 1.26$) than in the arrow condition ($M = 2.38$, $SD = 0.87$), and this main effect of route representation was statistically significant, $F(1, 6) = 9.557$, $p = 0.02$. There was no significant main effect for cue presence, $p = 0.92$.

Average visit duration was calculated as the average time between a spacebar press and release. For the cue presence manipulation, there was a trend for participants to have shorter visits in the highlighted condition ($M = 1.52$s, $SD = 0.54$s) than in the non-highlighted condition ($M = 1.92$s, $SD = 0.93$s), although this effect was not statistically reliable, $p = 0.06$. For the route representation manipulation there was also a trend for participants to have shorter visits in the text condition ($M = 1.63$s, $SD = 0.72$s) than in the arrow condition (1.81s, $SD = 0.84$s), but this effect was also not statistically reliable, $p = 0.1$. There was no significant effect for focus, $p = 0.64$.

Average drift during visits was calculated as the mean relative change in lateral position during visit events. For the manipulation of route representation, participants had less drift during visits in the text condition ($M = 0.29$m, $SD = 0.26$m) than in the arrow condition ($M = 0.55$m, $SD = 0.29$m), and this main effect of route representation was statistically significant, $F(1, 6) = 7.93$, $p = 0.03$. For the manipulation of task focus, there was a trend for participants in the driving-focus condition to have less drift during visits ($M = 0.19$, $SD = 0.24$) than participants in the navigating-focus condition (*M* = 0.64, *SD* = 0.41), but this effect was not statistically reliable, $F(1, 6) = 5.0$, $p = 0.07$. There was no significant main effect for cue presence, $p = 0.11$.

First and second visit analyses.

In this study we were also interested in how participants resumed the secondary navigating task, as a quick resumption will reduce the amount of distraction by the secondary device, and increase the amount of attention paid to the road. To determine resumption effects, the measures of visit duration and drift during visits were compared between first visits (where it would be expected that resumption is not present) and second visits (where it is expected that resumption is present). A 2x2x2x2 mixed factorial ANOVA with variables of task focus (driving; navigating), cue presence (non-highlighted; highlighted), route representation (arrows; text), and visit-type (first; second) was used for statistical analyses. Task focus was analysed as a between subjects variable, while cue presence, route representation, and visit-type were analysed as within-subject variables.

When considering the visit durations of both visit-types, participants had shorter second visit durations (*M* = 1.63s, *SD* = 0.71s) than first visit durations (*M* = 1.95s, *SD* = 0.68s), and this main effect of visit-type was statistically reliable, $F(1, 6) = 6.66$, $p = 0.04$. There was a trend for participants to have shorter visit durations in the highlighted-condition (*M* = 1.65s, *SD* = 0.55s) than the non-highlighted condition (*M* = 1.94s, *SD* = 0.8s), but this effect was not statistically reliable, $p = 0.07$. There were no significant main effects of route representation ($p = 0.21$) or task focus ($p = 0.86$)

For visit duration of the second visit only, there was a trend for participants to have shorter durations in the highlighted condition (*M* = 1.44s, *SD* = 0.56s) than in the non-highlighted condition (*M* = 1.81s, *SD* = 0.81s), but this effect was not statistically reliable, $F(1, 6) = 4.86$, $p = 0.07$. There were no significant main effects of task focus ($p = 0.86$) or route representation ($p = 0.21$). For the first visit only, there were no significant main effects of cue ($p = 0.14$), representation ($p = 0.37$), or task focus ($p = 0.84$).

An analysis of drift during visits was also carried out for the first and second visits. For first and second visits, there was a significant main effect of route representation, $F(1, 6) = 11.49$, $p = 0.02$; participants had less lateral drift during visits in the text condition (*M* = 0.35m, *SD* = 0.38m) than in the arrow condition (*M* = 0.52m, *SD* = 0.51m). There was also a trend for participants in the driving-focus condition to have less lateral drift during visits (*M* = 0.20m, *SD* = 0.34m) than participants in the navigating-focus condition (*M* = 0.68m, *SD* = 0.44m), but this effect was not statistically reliable, $p = 0.058$. There was no significant main effect of cue presence, $p = 0.14$.

For the first visit only, participants in the driving-focus group had less drift during visits (*M* = 0.18m, *SD* = 0.27m) than participants in the navigating-focus group (*M* = 0.67m, *SD* = 0.33m). This main effect of task focus was statistically significant, $F(1, 6) = 9.97$, $p = 0.02$. Participants had less lateral drift during first visits in the text condition (*M* = 0.3m, *SD* = 0.19m) than in the arrow condition (*M* = 0.55m, *SD* = 0.47m), and this main effect of route representation was also statistically significant, $F(1, 6) = 9.06$, $p = 0.02$. There were no significant effects for cue presence ($p = 0.1$).

For the second visit only, there were no significant effects for task focus ($p = 0.14$), cue presence ($p = 0.3$), or route representation ($p = 0.11$).

Combined measures.

In addition to the event-based measures, two additional measures were calculated by combining event-based measures. It was unclear from the visit data whether longer visits were a result encoding difficulty or encoding more items. To clarify the relationship between average visit duration and items encoded, the measure encoding rate was calculated by dividing the average visit duration by the number of actions following that visit. For the manipulation of task-focus, there was no significant main effect, $p = 0.78$. For the manipulation of cue presence, there was no significant main effect, $p = 0.12$. For the manipulation of route representation, there was no significant main effect, $p = 0.27$.

To gain a general overview of how much time was allocated to the navigating task, the measure total visit time was calculated by multiplying average visit duration and number of visits per trial. Participants in the text condition spent less time per trial visiting the navigator display in the text condition ($M = 5.33$s, $SD = 2.74$s) than in the arrow condition ($M = 7.12$s, $SD = 3.45$s), and this main effect of route representation was statistically significant, $F(1, 6) = 12.47$, $p = 0.01$. There was a trend for participants to spend less time looking at the navigating display in the highlighted condition ($M = 5.37$s, $SD = 2.58$s) than the non-highlighted condition ($M = 7.08$s, $SD = 3.59$s), but this effect was not statistically reliable, $p = 0.08$.

Post-visit measures.

Average post-visit duration was calculated as the time between a spacebar release and the next event (either trial finish if the list has been completed, or the next visit if the list has not been completed). For the manipulation of cue presence, participants had shorter post-visit durations in the highlighted condition ($M = 3.21$s, $SD = 1.23$s) than in the non-highlighted condition ($M = 3.96$s, $SD = 1.97$s), and this main effect of cue presence was statistically significant, $F(1, 6) = 11.14$, $p = 0.02$. There were no significant main effects for task focus ($p = 0.42$) or route representation ($p = 0.17$).

Average correction during post-visits was calculated as the mean relative change in lateral position during post-visit events. For the manipulation of route representation, participants corrected less during post-visit in the text condition ($M = 0.23$m, $SD = 0.17$m) than in the arrow condition ($M = 0.41$m, $SD = 0.35$m), and this main effect of route representation was significant, $F(1, 6) = 7.32$, $p = 0.04$. For the task focus manipulation, there was a trend for participants in the driving-focus condition to correct less post-visit ($M = 0.15$m, $SD = 0.18$m) than participants in the navigating-focus condition ($M = 0.48$m, $SD = 0.28$m), but this effect was not statistically reliable, $p = 0.07$. There was also a trend for participants to correct less post-visit in the highlighted condition ($M = 0.29$m, $SD = 0.31$m) than in the non-highlighted condition ($M = 0.34$m, $SD = 0.27$m), but this effect was not statistically reliable, $p = 0.1$.

3.3. Discussion

For the manipulation of task focus, the prediction that a speed-accuracy trade-off would occur between the two groups was supported: participants in the driving-focus group had better RMSE lateral deviation scores, and participants in the navigating-focus group had better trial times. This finding supports previous studies (Brumby et al., 2007, 2009; Schumacher et al., 2001; Wickens & Seidler, 1997) that have found that people flexibly adapt interleaving strategies to meet performance objectives, and that limits on cognitive resources force participants to accept a performance decrement in the low-priority task to meet these objectives. The prediction that participants in the driving-focus group would have more frequent visits of shorter duration than participants in the navigating-focus group was partially supported: while participants in the driving-focus group had more visits per trial and less actions per visit than participants in the navigating-focus group, the average visit durations between the two groups were not significantly different.

For the manipulation of cue presence, the prediction that a cue would assist resumption of the secondary task was partially supported: participants had significantly shorter visit durations in the highlighted-condition. Trial times were also faster in the highlighted-condition than in the non-highlighted condition. If the cue assisted secondary task resumption, this would lead to significantly shorter second visit durations, which is when participants are resuming the secondary task. However, the effect of cue presence on average second visit durations did not reach significance. Furthermore, the difference in total time spent visiting the navigator display did not reach significance.

Although previous studies by Czerwinski et al. (2000) and Cutrell et al. (2001) found that a similar salient highlight cue did not lead to significantly faster trial times, the highlight cue used in this experiment did lead to significantly faster trial times. The task from these studies and the current experiment differed significantly; for example, in these previous experiments it was unclear whether the external cue position, which was determined by manual cursor presses, was actually in sync with the participants' visual scanning activity, which would have made it an imprecise aid for task resumption. In contrast, the external cue used in this experiment was always in sync with the next actions to be executed, which made it a more reliable aid for task resumption. Even though the presence of the highlight cue did lead to faster trial times in this experiment, it is still unclear whether this benefit is due specifically to faster secondary task resumption, which was a prediction made based on memory-for-goals theory (Altmann and Trafton, 2002).

For the external representation manipulation, the prediction that text representations would lead to faster encoding and better secondary task performance was supported: participants in the text condition had shorter visit durations, encoded more items per visit, and had faster trial times. Furthermore, participants had less lateral deviation during visits in the text condition than the arrow condition, although this did not result in better overall driving performance. These findings differ from those of Chewar and McCrickard (2002), but there are several differences between their experiment and this experiment. Chewar and McCrickard (2002) found that route descriptions represented as single-arrows led to faster trial times, while this experiment compared route descriptions represented as text-lists performed better than route descriptions represented as arrow-lists. Furthermore, participants in the Chewar and McCrickard (2002) study had constant visual access to the route descriptions, while this experiment restricted visual access to force participants to rely on memory-intensive strategies. In summary, the text representation was better suited for this particular experiment task, which required fast encoding in short glances and memory-intensive strategies.

Taken altogether, the findings of this experiment support several of the predictions made, but a larger sample size would be required to produce more significant effects, especially for event-based measures which are more prone to variability. In this experiment, it was observed that participants would sometimes hold down the keyboard spacebar while maintaining focus on the driving task. As spacebar data was being used to infer when participants were looking at the navigator display, this created an internal validity issue. A second experiment with a larger sample size was carried out to rectify these issues.

CHAPTER 4. EXPERIMENT 2

A second experiment was conducted to address a potential methodological issue of the first experiment. It was noticed that in the first experiment, it was possible for participants to hold down the keyboard spacebar while focusing on the driving task. If spacebar data was to be used to infer when participants were looking at the navigator display, this created an internal validity issue. To increase the reliability of spacebar press data, the dual-task paradigm was changed so that pressing the spacebar would display the route description but at the same time occlude the driving simulator (see Figures 3.2.2 and 4.2.3). This change permits the participants to only focus visual attention on one task at a time and encourages participants to only press the spacebar when they are actually attending to the navigator display. Furthermore, a larger sample size was used in the second experiment to increase the likelihood that experiment manipulations would produce significant effects.

4.1. Method

Participants.

Participants were 18 students (five female), aged between 21- and 42-years (*M* = 28.33 years, *SD* = 6.04 years). All participants had a valid driver's license and at least two years of driving experience (*M* = 9 years, *SD* = 4.42 years). Participants were unpaid volunteers that were recruited through flyers and electronic mailing lists.

Design.

The experiment design was the same as the first experiment: a 2x2x2 mixed factorial design with the independent variable of task focus (driving-focus; navigating-focus) between-subjects and the independent variables of route representation (graphic; text) and cue presence (non-highlighted; highlighted) within-subjects. Task focus was assigned to participants in alternation and balanced across gender. The order of route representation and cue presence conditions were counter-balanced across participants to minimise order effects. The dependent variables collected in this experiment were root mean square error (RMSE) lateral deviation, trial time, number of visits per trial, average visit duration, average drift during visits, average post-visit duration, average correction during post-visits, and number of actions per visit.

Materials.

The physical set-up of the experiment was the same one used in the first experiment (see Figure 3.1.1 in previous chapter). The structure of the driving-task and navigating-task was the same as the first experiment, but a modification was made in the dual-task trials, such that pressing the keyboard spacebar occluded the driving display. This modification permitted participants to focus only on one task at a time. By occluding the driving display, participants were encouraged to only press the space bar when they were looking at the navigator display. It was hoped that making this modification would increase the validity of the spacebar press data, which is later analysed to infer when participants are focusing on the navigating task.

Procedure.

The general structure of the second experiment was the same as the first experiment, which consisted of two practice blocks and five experiment blocks. The participants first completed a single-task practice block for driving, followed by a single-task practice block for navigating. Then participants completed four dual-task blocks, with a block of single-task driving trials (to measure baseline driving performance) between the second and the third dual-task block. Following each dual-task block the participants were given a short break (30 seconds after the first and third dual-task blocks, 60 seconds after the second dual-task block). The structure of trials and the way errors were handled were the same as the first experiment.

4.2. Results

From the raw data we excluded error trials, as global measures (e.g. trial time, RMSE lateral deviation) needed to be compared across completed trials. Two participants were excluded for having a mean dual-task driving score that was more than two standard deviations above the mean for all participants. Of a total of 769 trials, 135 trials (17.56%) were excluded due to participant error, leaving 634 successful trials which were further analysed. The dependent measures of interest were lateral deviation from the centre, trial time, and eight other measures (see Table 3.2.1 in previous chapter). Unless otherwise stated, a 2x2x2 mixed factorial ANOVA with variables of task focus (driving; navigating), cue presence (non-highlighted; highlighted), and route representation (arrows; text) was used for statistical analyses. Task focus was analysed as a between subjects variable, while cue presence and route representation were analysed as within-subject variables. An alpha-level of 0.05 was used throughout.

Driving performance.

The dependent measure used to analyse overall driving performance was the root mean square error (RMSE) lateral deviation over the trial. The first analysis compared RMSE between the dual-task trials (compressed across display conditions) and the single-task baseline driving trials. The second analysis compared RMSE between different conditions for successful dual-task trials. The simulator logged the lateral distance of the vehicle from the lane centre at a rate of 200 Hz. The RMSE of these cumulative lateral deviation samples was then calculated over course of the trial (the time between the trial start message and the participant positioning the car in lane centre following route entry completion).

Figure 4.2.1 shows the RMSE lateral deviation of the two task-focus groups in the single-task driving block and the dual-task blocks. Participants had less lateral movement during the single-task driving block (M = 0.32m, SD = 0.07m) than the dual-task blocks (M = 0.72, SD = 0.31m). For dual-task blocks, participants in the driving-focus group had less lateral movement (M = 0.47m, SD = 0.1m) than participants in the navigating-focus group (M = 0.96m, SD = 0.24m).

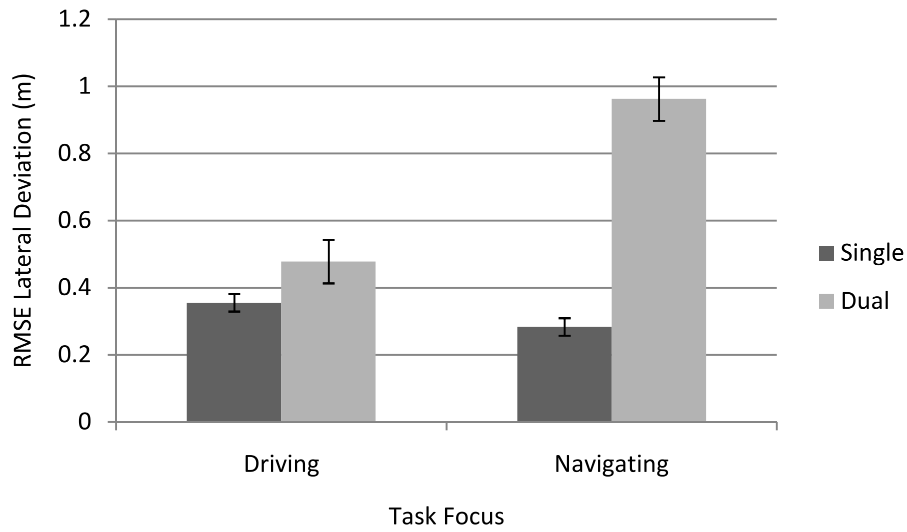

Figure 4.2.1. RMSE lateral deviation for single-task and dual-task trials for both task-focus groups. Error bars are standard error of mean.

A 2x2 mixed factorial ANOVA with the variable of task focus (driving-focus; navigating-focus) analysed between-subjects and the variable of experiment part (single-task; dual-task) analysed within-subjects. A main effect of experiment part that was highly statistically significant was found, $F(1, 14) = 68.33$, $p < 0.001$. There was also a statistically significant main effect of task focus, $F(1, 14) = 16.36$, $p = 0.001$. Furthermore, there was a statistically highly significant interaction between experiment part and focus, $F(1, 14) = 32.87$, $p < 0.001$.

For dual-task blocks, participants had less lateral movement in the text condition (M = 0.65m, SD = 0.25m) than in the arrow condition (M = 0.78m, SD = 0.43m), and this main effect of route representation was statistically significant, $F(1, 14) = 6.284$, $p = 0.03$. There was no significant effect of cue presence, $p = 0.28$.

Figure 4.2.2 shows RMSE lateral deviation for both task focus groups in the two route representation conditions. There was a trend for participants in the navigating-focus condition to have less lateral movement in the text condition than in the arrow condition, while participants in the driving-focus condition had equivalent lateral movement for both route representations. However, this interaction between task focus and route representation was not statistically reliable, $F(1, 14) = 4.06$, $p = 0.06$.

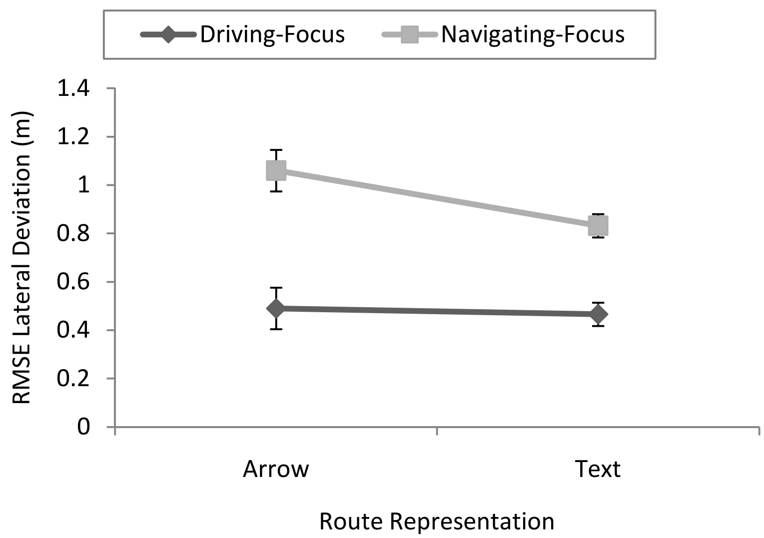

Figure 4.2.2. Interaction between task-focus and route representation for RMSE lateral deviation. Error bars are standard error of mean.

Navigating task performance.

The dependent measure used to analyse overall navigating task performance was trial time, which was the time between the trial start message and the participant positioning the car in lane centre following route entry completion. Participants in the navigating-focus condition had significantly faster trial times (M = 14.1s, SD = 3.46s) than participants in the driving-focus condition (*M* = 27.3s, *SD* = 6.29s), and this main effect of task focus was statistically highly significant, $F(1, 14) = 37.05$, $p < 0.001$. For the cue presence manipulation, participants had faster trial times in the highlighted condition (*M* = 19.23s, *SD* = 7.65s) than in the non-highlighted condition (*M* = 22.17s, *SD* = 8.85s), and this main effect of cue presence was statistically significant, $F(1, 14) = 14.02$, $p = 0.002$. For the route representation manipulation, participants had significantly faster trial times in the text condition (SD = 19.17s, *SD* = 7.81s) than in the arrow condition (*M* = 22.23s, *SD* = 8.69s), and this main effect of route representation was statistically highly significant, $F(1, 14) = 46.33$, $p < 0.001$.

Event-based measures.

Six measures of interest were used to consider task interleaving during dual-task trials: number of visits per trial, number of actions per visit, average visit duration, average drift during visits, average post-visit duration, and average correction during post-visits. These measures were based on two types of trial events: visits were when the participant pressed the keyboard spacebar to view the route description on the navigator display, and post-visits were when the participant released the spacebar and returned focus to the driving simulator (see Figure 4.2.3).

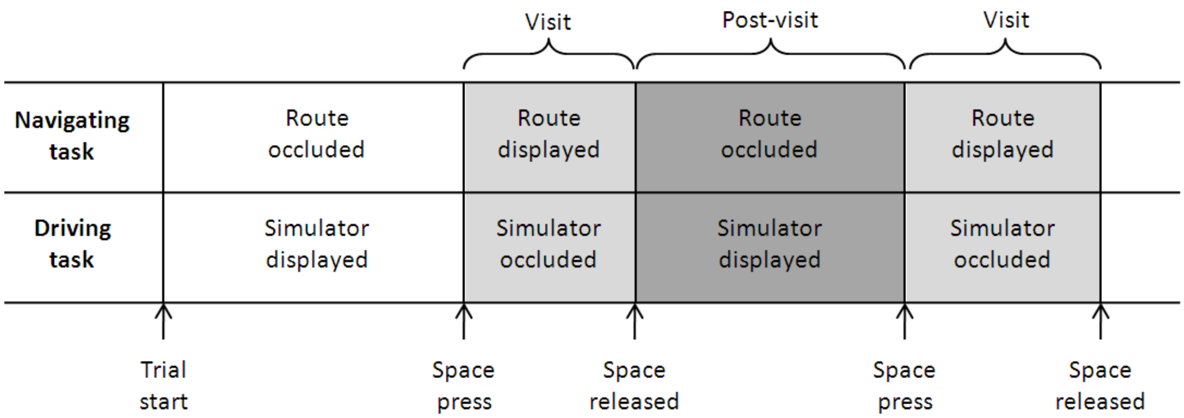

Figure 4.2.3. Visit and post-visit trial events for second experiment.

Visit measures.

Number of visits per trial was calculated as the mean number of distinct spacebar presses over the course of a trial. For the manipulation of route representation, participants made less visits in the text condition ($M = 3.61$, $SD = 1.16$) than in the arrow condition ($M = 4.27$, $SD = 1.59$), and this main effect of route representation was statistically significant, $F(1, 14) = 13.06$, $p = 0.003$. For the manipulation of task focus, there was a trend for participants in the navigating-focus condition to have less visits per trial ($M = 3.37$, $SD = 1.27$) than participants in the driving-focus condition ($M = 4.51$, $SD = 1.35$), but this effect was not statistically reliable, $p = 0.09$. There was no significant main effect for cue presence, $p = 0.37$.

Number of actions per visit was calculated by counting the number of route directions entered following each visit to the navigator display. Participants in the navigating-focus condition entered more actions per visit ($M = 3.23$, $SD = 1.08$) than participants in the driving-focus condition ($M = 2.34$, $SD = 0.69$), and this main effect of task focus was significant, F(1,

14) = 4.74, $p = 0.05$. Participants entered more actions per visit in the text condition ($M = 3.0$, $SD = 1.01$) than in the arrow condition ($M = 2.63$, $SD = 1.01$), and this main effect of route representation was significant, $F(1, 14) = 14.78$, $p = 0.002$. There was no significant main effect for cue presence, $p = 0.43$.

Average visit duration was calculated as the time between a spacebar press and release. For average visit duration, there was a significant main effect for cue presence, $F(1, 14) = 14.13$, $p = 0.002$; participants had shorter visits in the highlighted condition ($M = 1.26$s, $SD = 0.70$s) than in the non-highlighted condition ($M = 1.59$s, $SD = 0.8$s). There was also a significant main effect for route representation, $F(1, 14) = 5.25$, $p = 0.04$; participants had shorter visits in the text condition ($M = 1.3$s, $SD = 0.63$s) than in the arrow condition ($M = 1.53$s, $SD = 0.88$s). There was no significant main effect for focus, $p = 0.34$.

Average drift during visits was calculated as the mean relative change in lateral position during visit events. There was a significant main effect for cue presence, $F(1, 14) = 6.25$, $p = 0.03$; participants had less drift during visits in the highlight condition ($M = 0.42$m, $SD = 0.48$m) than in the non-highlighted condition ($M = 0.73$m, $SD = 0.80$m). There were no significant main effects for task focus ($p = 0.9$) or route representation ($p = 0.12$).

First and second visit analyses.

As in the first experiment, the event-based measures of visit duration and drift during visits were compared between first and second visits to determine resumption effects. A 2x2x2x2 mixed factorial ANOVA with variables of task focus (driving; navigating), cue presence (non-highlighted; highlighted), route representation (arrows; text), and visit-type (first; second) was used for statistical analyses. Task focus was analysed as a between subjects variable, while cue presence, route representation, and visit-type were analysed as within-subject variables.

For first and second visits, participants had shorter visit durations in the highlighted condition ($M = 1.36$s, $SD = 0.78$s) than in the non-highlighted condition ($M = 1.61$s, $SD = 0.85$s), and this main effect of cue presence was statistically significant, $F(1, 14) = 9.56$, $p < 0.01$. There was also a trend for participants to have shorter visit durations in the text condition ($M = 1.38$s, $SD = 0.68$s) than in the arrow condition ($M = 1.59$s, $SD = 0.94$s), but this effect was not statistically reliable, $F(1, 14) = 4.21$, $p = 0.06$. There was no significant main effect for task focus ($p = 0.3$) or visit-type ($p = 0.11$).

Figure 4.2.4 shows an interaction between visit-type and cue presence. First visit durations in non-highlighted and highlighted conditions are equivalent ($M = 1.5$s, $SD = 0.77$s; $M = 1.4$s, $SD = 0.73$s), but for the second visit participants had significantly shorter visit durations in the highlighted condition ($M = 1.32$s, $SD = 0.78$s) than in the non-highlighted condition ($M = 1.73$s, $SD = 0.93$s). This interaction between visit-type and cue presence was statistically highly significant, $F(1, 14) = 25.16$, $p < 0.001$.

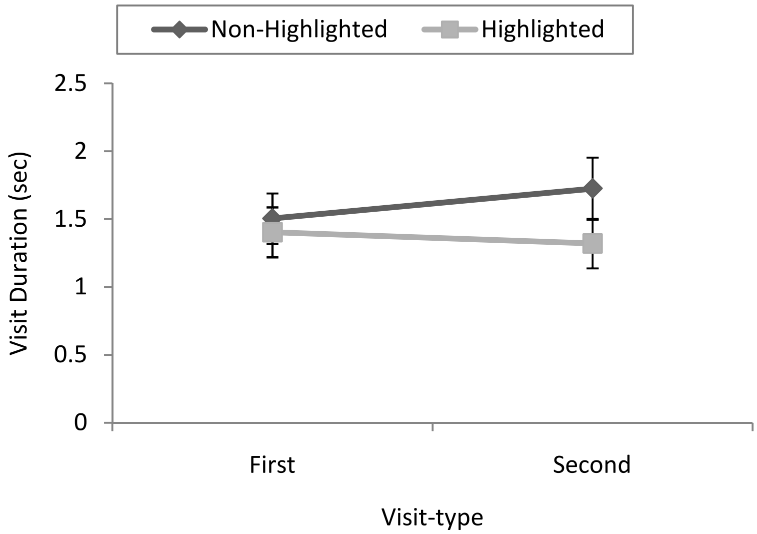

Figure 4.2.4. Interaction between visit-type and cue presence for average first and second visit duration. Error bars are standard error of mean.

For the first visit only, participants had significantly shorter visit durations in the text condition (M = 1.35s, SD = 0.67s) than in the arrow condition (M = 1.5s, SD = 0.88s), and this main effect of route representation was statistically significant, $F(1, 14) = 5.92$, $p = 0.03$. There were no significant effects of cue ($p = 0.25$) or task focus ($p = 0.21$). For the second visit only, participants had significantly shorter visits in the highlighted condition (M = 1.32s, SD =0.78s) than in the non-highlighted condition (M = 1.73s, SD = 0.93s), and this main effect of cue presence was statistically significant, $F(1,14) = 19.75$, $p = 0.001$. There were no significant effects for route representation ($p = 0.11$) or task focus ($p = 0.41$).

For drift during first and second visits, participants had less lateral drift in the highlighted condition (M = 0.5m, SD = 0.59m) than in the non-highlighted condition (M = 0.77m, SD = 0.98m), and this main effect of cue presence was statistically significant, $F(1, 14) = 4.89$, $p =$ 0.04. There was also a trend for participants to have less drift in their first visit (M = 0.55m, SD =

0.6m) than their second visit (*M* = 0.72m, *SD* = 0.99m), but this effect was not statistically reliable, $p = 0.09$. There was no significant main effect for task focus ($p = 0.38$) or route representation ($p = 0.17$).

Figure 4.2.5 shows an interaction between visit-type and cue-presence. For the first visit, participants had equivalent lateral drift in non-highlighted and highlighted condition, but for the second visit participants had less lateral drift in the highlighted condition than in then non-highlighted condition. This interaction between visit-type and cue presence was statistically significant, $F(1, 14) = 14.06$, $p = 0.002$.

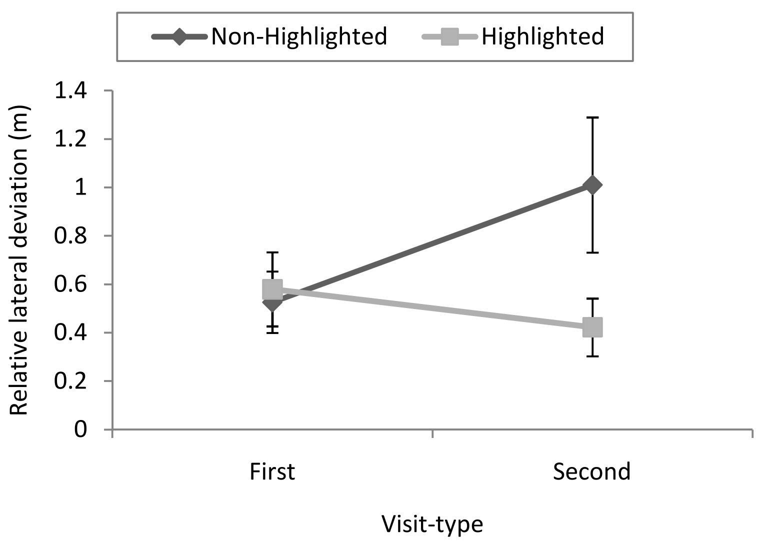

Figure 4.2.5. Interaction between visit-type and cue presence for drift during first and second visit. Error bars are standard error of mean.

For the first visit only, participants had less lateral drift in the text condition (*M* = 0.44m, *SD* = 0.41m) than in the arrow condition (*M* = 0.67m, *SD* = 0.74m), and this main effect of route representation was statistically significant, $F(1,14) = 0.03$. There were no significant effects of cue presence ($p = 0.61$) or task focus ($p = 0.42$). For the second visit only, participants had less lateral drift in the highlighted condition (*M* = 0.42m, *SD* = 0.52m) than in the non-highlighted condition (*M* = 1.01m, *SD* = 1.24m), and this main effect of cue presence was statistically significant, $F(1,14) = 10.31$, $p = 0.006$. There were no significant effects for representation ($p = 0.76$) or task focus ($p = 0.37$).

Combined measures.

In addition to the event-based measures, two additional measures were calculated by combining event-based measures. For the combined measure encoding rate (average visit duration divided by actions per visit), participants spent less time encoding each item in the highlighted condition (*M* = 0.43s, *SD* = 0.13s) than in the non-highlighted condition (*M* = 0.59s, *SD* = 0.25s), and this main effect of cue presence was statistically significant, $F(1, 14) = 17.99$, $p = 0.001$. Participants spent less time encoding each item in the text condition (*M* = 0.44s, *SD* = 0.17s) than in the arrow condition (*M* = 0.57s, *SD* = 0.23s), and this main effect of route representation was statistically significant, $F(1, 14) = 17.54$, $p = 0.001$. There was no significant main effect for task focus, $p = 0.73$.

For the combined measure total visit time (average visit duration multiplied by number of visits per trial), participants spent less time looking at the navigator display in the highlighted condition (*M* = 4.19s, *SD* = 1.4s) than in the non-highlighted condition (*M* = 5.62s, *SD* = 2.08s), and this main effect of cue presence was statistically highly significant, $F(1, 14) = 23.51$, $p < 0.001$. Participants spent less time looking at the navigator display in the text condition (*M* = 4.28s, *SD* = 1.54) than in the arrow condition (*M* = 5.54s, *SD* = 2.04s), and this main effect of route representation was statistically highly significant, $F(1, 14) = 32.17$, $p < 0.001$. There was no significant main effect for task focus, $p = 0.72$.

Post-visit measures.

Average post-visit duration was calculated as the time between a spacebar release and the next event (either trial finish if the list has been completed, or the next visit if the list has not been completed). For average post-visit duration, there was a highly significant main effect of task focus, $F(1, 14) = 20.65$, $p < 0.001$; participants in the driving-focus condition had longer post-visit durations (M = 5.4s, SD = 1.76s) than participants in the navigating-focus condition (M = 2.6s, SD = 0.63s). There were no significant main effects for cue presence ($p = 0.6$) or route representation ($p = 0.23$).

Average correction during post-visits was calculated as the mean relative change in lateral position during post-visit events. There was a trend for participants to correct more post-visit in the non-highlighted condition (M = 0.36m, p = 0.4m) than in the highlighted condition (M = 0.21m, SD = 0.24m), but this effect was not statistically reliable, $p = 0.054$. There were no significant main effects for task focus ($p = 0.13$) or route representation ($p = 0.18$).

4.3. Discussion

For the manipulation of task focus, the prediction that a speed-accuracy trade-off would occur between the two groups was further supported: participants in the driving-focus group had better RMSE lateral deviation scores, and participants in the navigating-focus group had better trial times. This result was the same as the first experiment, and further supports previous studies (Brumby et al., 2007, 2009; Schumacher et al., 2001; Wickens & Seidler, 1997), which suggests that people flexibly adapt interleaving strategies to meet performance objectives.

The prediction that participants in the driving-focus group would have more frequent visits of shorter duration than participants in the navigating-focus group was again partially supported: as in the first experiment, participants in the driving-focus group had significantly less actions per visit. Although participants in the driving-focus made significantly fewer visits per trial in the first experiment, this difference did not reach significance in the second experiment. Furthermore, for both experiments participants in the driving-focus group did not have significantly shorter durations than participants in the navigating-focus group.

These mixed results from event-based measures may have resulted from varying strategies within task focus groups. Specifically, the navigating-task used in these experiments is new, and it's possible that several strategies exist that could produce a fast trial time. Although a majority of navigating-focus participants opted for a strategy of long infrequent visits to the navigating display, there were participants that achieved relatively fast trial times by making frequent short visits, which would have produced an average visit duration and number of visits per trial similar to the driving-focus group. Variability within the navigating-group may have resulted from individual differences in working memory capacities (Just & Carpenter, 1992), which would have led to participants with less working memory capacity to make more visits to complete the navigating-task.

For the manipulation of cue presence, the prediction that a cue would assist resumption of the secondary task was supported: Figure 4.2.4 shows that average second visit durations were significantly shorter in the highlighted condition than in the non-highlighted condition, which is when participants were resuming the secondary task. For the first visit, which does involve mid-task resumption, visit durations between the highlighted and non-highlighted conditions were equivalent, which suggests that the highlight cue is used specifically for mid-task resumption and reorientation. This effect of cue presence on second visit duration was not significant in the first experiment, but a larger sample size in the second experiment may have led to a significant effect.

This finding provides evidence for memory-for-goals theory (Altmann & Trafton, 2002), which proposes that cues from the task environment help by reactivating suspended goals in a task-switching paradigm. Unlike previous studies (Ratwani & Trafton, 2006; Trafton, et al. 2005), which looked at resumption of a focal task, these experiments demonstrate that external cues are also help resumption of a secondary task on a peripheral display. Furthermore, Figure 4.2.5 shows that a highlight cue also reduces drift during mid-task resumption, which further suggests that external cues that help resumption can be important to display design for safety-critical tasks.

For the manipulation of route representation, the prediction that text representations would lead to faster encoding and better secondary task performance was supported: participants in the text condition had shorter visit durations, encoded more items per visit, and had faster trial times. This replicated the results from the first experiment. Although participants in the text condition did not have less drift during, they did have better overall driving performance. The superiority of text representations for the secondary task in this experiment may have been a result of verbal recoding (Brandimonte & Gerbino, 1993; Brandimonte et al., 1992), but it is still unclear whether this was actually the case. These findings provide evidence for Zhang and Norman's (1994) representation effect; even when two representations convey the same meaning, one type of external representation may have advantages over others in a particular task.

Taken altogether, the findings of this experiment support several of the predictions made, and with a larger sample size than the first experiment produced further evidence for the effects of task focus, external cue presence, and external representation. The following chapter summarises the general findings of both experiments in the context of the relevant literature, and identifies limitations of the current experiments, future directions, and implications for design.

CHAPTER 5. GENERAL DISCUSSION

The results from these experiments demonstrated that performance objectives, external cues, and external representations influenced task interleaving strategies. Participants flexibly adapted strategies to meet their performance objectives, and focusing primarily on one task led to a performance decrement on the other task. Goal-relevant external cues supported task resumption, and external representations that supported verbal memory improved secondary task performance. These results suggest that information design can allow tasks to be executed more efficiently, which in turn can lead to less interference in a dual-task situation. In this general discussion we will review each of these factors, followed by a discussion of limitations and future directions, as well as implications for design.

5.1. Performance objectives and task interleaving strategies

The results from both experiments support the prediction that a speed-accuracy trade-off would occur if participants prioritise one task; participants in the driving-focus condition had better overall driving performance but worse overall navigating task performance than participants in the navigating-focus condition. These data are consistent with the findings of Brumby et al. (2007) and Wickens & Seidler (1997); participants are able to flexibly adapt their behaviour to explicitly defined performance objectives.

The results suggest that participants' task interleaving strategies are being driven by a combination of performance objectives, cognitive constraints, and temporal constraints.

Participants in the navigating-focus group entered more actions per visit, which is an example how performance objectives influenced interleaving strategy. In the navigating task, working memory load determined how many route description items were encoded and memorised in a short glance. Interleaving strategy may be time-driven to the extent that participants felt pressured to return to the driving-task to avoid severe lateral deviation. However, when processing information from the navigator display participants had longer visits if the information was more difficult to encode or more difficult to resume.

The event-based measures do not fully support the prediction that participants in the driving-focus would have more frequent visits of shorter duration. One possible explanation is that variability of strategies may have been present within focus-groups, particularly in the navigating-focus group where there may be multiple ways to produce a fast trial time. Further analyses of the data would be needed to determine if this were the case.

5.2. Information presentation effects

The current research was also interested in how information presentation could support task interleaving. To investigate these effects, these experiments manipulated the presence of external cues and the external representation of route descriptions. The results suggest that external cues reduce resumption lag and that external representations can improve encoding efficiency. Both of these factors ultimately lead to improved secondary task performance.

External cues have been shown to reduce resumption lag (Ratwani & Trafton, 2006; Trafton et al., 2005), and analyses of the first and second visit durations demonstrate that external cues supported resumption of the navigating task. These findings support previous findings (Ratwani & Trafton, 2006; Trafton et al., 2005) and memory-for-goals theory (Altmann & Trafton, 2002), suggesting that external cues are helpful for helping people remember suspended goals.

Text representation led to better navigating task performance and reduced interference with the primary task. These findings provide evidence for Zhang and Norman's (1994) representation effect; even when two representations convey the same meaning, one type of external representation may have advantages over others in a particular task. Text representation was superior in this task, which was memory-intensive, while Chewar and McCrickard (2002) found graphic representations superior. Scaife and Rogers (1996) suggest that the superiority of one representation in one task can not necessarily be generalised to other tasks, so this discrepancy is not surprising, given the considerable differences between the two experiments.

5.3. Limitations and future directions

Although results between the first and second experiments were mostly consistent, there were some differences amongst the event-based findings. To make sense of these differences, a meta-analysis should be performed to confirm whether the first and second experiments are indeed comparable (Rosenthal, 1991). Because of time constraints related to this thesis project, there was not enough time to complete a meta-analysis, but this will be pursued in the future.

One limitation of the current study is that the driving task is artificial and overly simple. Participants only had to be concerned with the lateral position of the vehicle, while in a realistic driving scenario they would need to remain constantly vigilant of numerous factors, such as other vehicles, traffic lights and signs, as well as an upcoming destination. That being said, effects that are found in driving simulator studies tend to also found in real driving (Reed & Green, 1999).

Although the secondary task used in these experiments did not have an explicit task-structure, it is possible that participants may have used strategies that imposed structure on the task. For example, participants may have used pattern-based strategies, such as interleaving after a chunk of repeating directions (e.g. “Right-Right-Right”). Another way participants could have imposed structure on the task would be to use a fixed chunk structure (e.g. consistently chunking lists of 10 directions as 5-5 or 3-3-4. If either of these strategies were used, it would suggest that people actively seek opportunities to reduce perceptual and memory load by imposing structure on tasks that are not explicitly structured.

5.4. Implications for design

Although tasks determine how users are going to behave to an extent, designers need to also consider the motivations of users. Especially when designing for multitasking environments, consideration needs to be given to whether one is designing for a primary task that users are going to give priority to, or whether one is designing for a secondary task that is not going to receive as much attention. In the case of secondary in-vehicle devices, it must be assumed that perceptual and cognitive resources are going to be scarcely allocated to secondary tasks, and information should be presented in a way that can be quickly processed and easy to resume. The implementation of goal-relevant external cues could reduce the time needed to acquire information from a secondary display by reducing resumption lag, and choosing the external representation most appropriate for the task can make encoding and memorisation more reliable and efficient.

CHAPTER 6. CONCLUSION

In the introduction, a scenario was presented where a person dialed a phone number while driving. Several factors were considered that could possibly influence dual-tasking strategy: subtask boundaries, performance objectives, memory load, and perceptual encoding. The factors of performance objectives, memory load, and perpetual encoding were studied in a dual-tasking paradigm, and it was found that all of these factors influenced interleaving behaviour. The results have provided evidence that high-level strategies are adapted to meet performance objectives, and that low-level strategies are adapted according to the memory and perceptual demands of information displays. These findings extend understanding of factors that drive dual-task interleaving, and have implications for the design of information displays in multitasking environments. By providing goal-relevant cues and external representations that are appropriate to the task, designers can reduce the demands of distracting secondary tasks and encourage safe behaviour.

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APPENDIX A. EXPERIMENT INSTRUCTION SCRIPT

Beginning of the experiment:

"This experiment is interested in how drivers do two things at the same time. In this experiment you will be performing two tasks: one of the tasks will be driving the simulator. The goal of driving the simulator is to use the steering wheel to keep the car in the centre lane. If you do not correct the car, it will veer off to the side. The other task you will be performing will be entering directions from the navigation display which is located to your left. You will be reading a list of simple instructions from the navigation display and entering them into the steering wheel using the paddle controls under the steering wheel. I will give you further instructions on these tasks later. The general structure of the experiment will be: first, you will practice driving the simulator, then you will practice entering directions from the display, then you will have four blocks where you are doing both at the same time. Halfway through you will be five trials where you are just driving. These trials will allow us to measure how well you drive when you are focused on just driving."

Prior to driving practice (single-task):

"For the first part of this experiment, you will practice driving the simulator. You will have five trials. Each trial will last thirty seconds and at the end of thirty seconds you will receive feedback in terms of your lateral deviation. Your lateral deviation is how far you are from the centre of the lane, and lower lateral deviation scores are better."

Prior to navigating practice (single-task):

"For the next part of this experiment, you will practice using the navigation display. On this side display to your left, there will be a list of ten instructions and the list items are either going to be left or right. You enter these instructions using the indicators on the sides of the steering wheel. When you press the indicators, make sure that it is a distinct press, otherwise the experiment may not recognise it."

"There will be different types of lists throughout this experiment—for example, some of the lists will have left or right written in text, and some of the lists will have arrows pointing left or right. Some of the lists will have a highlight indicating your current place in the list, and some of the lists will have no highlight at all. This list will be hidden by default. In order to view the list you will need to hold down the space bar, then release the space bar when you are ready to enter directions. There is no limit the number of times you can press the space bar."

"You will be given feedback in terms of how quickly you complete the list, in seconds. If you make an error, the trial will finish immediately and you will be given a score of sixty seconds. Before the trial starts, you will see a screen that will tell you what the following lists will look like. For example, it may say 'Highlight ON, Text list' or 'Highlight will NOT be used, Arrow List.'"

Prior to dual-task blocks:

"Now we are going to start the blocks where you are doing both tasks at the same time. So now there will be two things to think about—keeping the car in the centre and entering the list."

[Instruction of task focus and feedback]

"At the beginning of the first trial, you will see a pop-up window that will say 'Accelerating. Wait and stay in centre.' When the car has accelerated to full-speed, the pop-up window will say 'Trial start.' At the start of the trial, first you make sure that your car is in the centre lane. If you are too far to the right or the left, you will not be able to access the list. When you are in the centre lane you may begin entering the list. When you are done with the list, you will again have to return to the centre of the lane to complete the trial."

"A block will continue until you complete ten trials successfully. This means that if you make errors, you will have to do extra trials. Following the end of every fifth trial, the simulator will stop and restart. So again, you will have four dual-tasking blocks, and halfway through you will complete some single-task driving trials. There will be short breaks between each block."

"Do you remember what your priority is?" [Prompt participant to repeat their priority to ensure that they understand].

[Ask the participant if they have any questions.]

The following instruction was given only to participants in Study 2:

“When you press the space bar, the list will show, but the simulator will be covered with a black box. The simulator will continue running even though it is covered. When you release the space bar the simulator will be shown again.”

Driving-focus priority instructions:

For this experiment, you are to prioritise keeping the car in the centre. So although we want you to enter the list within a reasonable amount of time, the most important thing is driving the car safely. You will always be given feedback in terms of your lateral deviation.

Navigating-focus priority instructions:

For this experiment, you are to prioritise entering the route directions quickly. So although we want you to keep the car reasonably in the centre, the most important thing is entering the directions quickly. You will always be given feedback in terms of your trial time.

APPENDIX B. POST-EXPERIMENT QUESTIONNAIRE

Please fill in the answer that most suits your situation

Sex: female / male Age: ____ years

How long do you have your driver's license? ____ years

How many hours do you drive a month, approximately? ____hours

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How often do you use a GPS device for walking?

1	2	3	4	5
Never	Rarely	Sometimes	Often	Always

How often do you use a GPS device for driving?

1	2	3	4	5
Never	Rarely	Sometimes	Often	Always

How often do you use online routes/maps (printed or on a device) for walking?

1	2	3	4	5
Never	Rarely	Sometimes	Often	Always

Have you ever used online routes/maps (printed or on a device) for driving?

1	2	3	4	5
Never	Rarely	Sometimes	Often	Always

Have you used a particular strategy during the experiment? If so, could you explain your strategy?

………
………
………
………
…………………………………………………………………………………………………

Did you find any list styles easier than others? Explain…

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