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Natural Break Points: Utilizing Motor Cues when Multitasking

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We investigate how people utilize motor preparation time under varying task objectives as a cue to switch between tasks when dialing and driving. Previous research has shown that people tend to switch between tasks at positions where a chunk of digits is retrieved from memory. If the number of chunks is minimized, do people use motor preparation time as a cue to switch between tasks instead? A study was conducted in which participants drove a simulated vehicle while also dialing two phone numbers that contained sets of repeating digits. Participants tended to switch between tasks after typing in a complete set of repeating digits. This effect took precedence over cognitive cues, and was robust when different relative priorities for the two tasks were adhered to (focus on driving, or on dialing). However, when participants prioritized driving they invested more in steering control. Limitations and implications of the work are discussed.

INTRODUCTION

Imagine you are running five minutes late for a meeting. You write a text message on your outmoded mobile phone saying, “Running late”. Assuming that you do not have T9 predictive text on the phone, the pattern of key entries will be: 777-88-66-66-444-66-4->-555-2-8-33. Now imagine that this was done while driving, as people continue to do despite legislative actions to outlaw such behavior (e.g., Diels, Reed, & Weaver, 2009). When would you pause to check on the road ahead? One strategy might be to interleave attention only after entering a whole word (i.e., only after dialing 777-88-66-66-444-66-4 for the word ‘Running’). This might seem to be an exceptionally reckless strategy as it takes the eyes off the road for a long period of time. A more conservative strategy might be to interleave after entering individual letters (i.e., interleaving after dialing 777 for ‘R’). In this case, the eyes are more frequently returned to the road ahead: in between each letter. But what about that middle double N in the word running? A short pause is necessary in between the two sets of 6s for the digit to be generated, but would you utilize the pause to check on steering? Again, perhaps this is dependent on how quickly you feel you need to write the message. This paper investigates how people utilize motor cues under varying task objectives in a situation similar to the one outlined above: manually dialing a number while driving.

Previous research on multitasking has shown that people tend to switch between tasks at subtask boundaries. At these points, mental workload decreases (Bailey & Iqbal, 2008), resources become available for other processes and tasks (Salvucci & Taatgen, 2008; Wickens, 2002), and interruption switch costs are minimized (Altmann & Trafton, 2002).

These general findings translate well to studies on performing secondary tasks while driving. Notably, when given the task to dial a phone number while driving, drivers tend to switch once they have dialed a chunk (i.e., a group) of digits that they have represented as one unit in memory (Salvucci, 2005). For example, when dialing a typical Northern American phone number, the pattern complies with the way the number is presented in (and learned from) a phonebook: xxx-xxx-xxxx (where ‘x’ denotes a digit and ‘-’ denotes a point of interleaving). Typing in a complete chunk of digits into the phone before switching back to driving reduces resumption costs (i.e., having to recall which digit of the chunk was typed last). In addition, the eyes and hands are available for the driving task, while the next set of digits is retrieved from memory.

Here we consider how more basic motor cues might interact with cognitive ones. As set out in our example, a relevant motor cue in a dialing while driving scenario can be how easy it is to type the next digit. For each keypress two phases can be distinguished (Rosenbaum, 1991). During the *preparation phase* the motor movement is prepared, among other things by acquiring the position of the target that needs to be pressed. During the subsequent *execution phase* the physical action (i.e., the keypress) is performed.

In the case of typing a repeating digit, the preparation phase is relatively short, as the finger is already on top of the to-be-pressed key. This makes it faster to type a repeating digit (e.g., “22”) compared to having to relocate the finger to another digit (e.g., “29”), particularly if the digits are relatively far apart on the phone. In a dual-task situation, preparing a finger movement to press a different key might serve as a cue to switch. Alternatively people might be guided by internal memory constraints (cf., Salvucci, 2005). We will investigate this in the current study.

In addition, any effect that motor and memory cues can have on when people interleave might be overwritten by strategic decisions, such as task priorities (cf., Navon & Gopher, 1979; Norman & Bobrow, 1975). Previous research has shown that task objective has a strong effect on dual-task performance(e.g., Brumby, Salvucci, & Howes, 2009; Horrey, Wickens, & Consalus, 2006; Janssen & Brumby, in press) and on task interleaving strategy. For example, Brumby, Salvucci and Howes (2009) found that priorities overshadow cognitive cues for task interleaving. In their study, participants suspended dialing for driving at chunk boundaries (i.e., xxx-xxx-xxxx) when told to prioritize safe driving over fast dialing. However, in the inverse situation, where fast dialing was prioritized over safe driving, the effect of chunk boundaries was lost. Does this result also transfer to situations where motor preparation time might influence switch costs?

In the current study, we consider the influence of both motor cues (i.e., whether there is a motor preparation phase required or not) and task priority on how people choose to interleave a secondary dialing task while driving a simulated vehicle. Participants were required to dial an 11-digit phone number while driving. We used two phone numbers that adhered to a typical UK structure, with two sets (or chunks) of digits of the form xxxxx – xxxxxx. As there was only one chunk boundary in the number, we could investigate the effects of motor cues on the decision of when to interleave tasks without too much interference from cognitive cues.

Each of the two phone numbers used in the study contained sets of repeating digits, but differed in the positions at which the repetitions occurred. Critically, in one number the repeating digits crossed the chunk boundary, while in the other a change in digit corresponded with the chunk boundary. A critical question addressed by this study was: Do people use the chunk boundary to guide task switching even when motor cues favor a delay?

To address this question we consider total dialing time and average lateral deviation during the trial. In addition, we will inspect steering movement data in between each successive keypress to help identify the dual-task interleaving strategy used. If any effects of motor cues on strategy are found, we expect them to be most prominent in situations where safe driving is prioritized over fast dialing (cf., Brumby, et al., 2009). Alternatively, it might be that effects of motor cues are more prominent than effects of memory, and that therefore these will also be present in the dialing focus condition.

METHOD

Participants

Twelve participants (8 female) from the UCL subject pool participated for monetary compensation of ten pounds. The mean age was 28.8 years (*SD* = 6.0). All participants had their driver's license for a minimum of two years.

Design

The experiment followed a 2 x 2 (phone number x task objective) within-subjects design. The two phone numbers contrasted in the positions of the repeating digits (see materials). Task objective was either to prioritize safe driving over fast dialing (from now on referred to as "driving focus") or to prioritize fast dialing over safer driving ("dialing focus"). Baseline performance was measured in single-task trials.

Materials

A Logitech G25 steering wheel and Nokia 6300 mobile phone were used. Both were desktop-mounted, with the phone positioned to the left of the driver. The driving environment was projected onto a 30-inch monitor in front of the participant. The software was based on that used by Salvucci and Beltowska (2008). It sampled basic measures of the car (e.g., position on the road, steering angle) at a rate of 50 Hz, and registered keypresses on the phone.

The driving environment was drawn from a first-person perspective. Participants drove in the middle of a three-lane highway at a constant speed of 88.5 km/h behind a lead vehicle at a fixed distance of 30 meters. Noise was added to the vehicle dynamics. In effect this made the car drift away from lane center in between steering movements.

For the dialing task, two 11-digit phone numbers were used. Both numbers adhered to a typical UK structure, with two groups of five and six digits respectively – both containing sets of repeating digits. In the *congruent number*, one of the switches between groups of repeating digits was congruent with the position of a switch in chunks (i.e., one group ended after the fifth digit, another started at the sixth digit). In the *incongruent number*, one of the groups of repeating digits transcended the chunk boundary. The digits of different groups of repeating digits were chosen such that they were spaced far apart on the phone (e.g., "72" and "49" instead of "47" and "78"). This way the contrast in dialing time between two repeating digits versus two non-repeating digits was increased. The resulting numbers were 07333-888111 (congruent number) and 07722-229944 (incongruent number).

To start and finish dialing, participants had to press '#' on the phone. Any errors that were made needed to be corrected. Pressing the '*' button deleted the last digit from the sequence of digits dialed. Therefore, mistakes made earlier required multiple corrections. This time consuming action encouraged accurate performance.

Procedure

The experiment started with ten single-task driving trials. This was followed by two experimental blocks. Each block had the same structure: (1) Participants learned a new phone number over the course of 10 trials, (2) they performed 5 single-task dialing trials, (3) they performed 15 dual-task driving + dialing trials with priority condition A (driving focus or dialing focus), and (4) they performed 15 dual-task driving + dialing trials with priority condition B. The structure in the second block mimicked that of the first block, but for a different phone number. The order of the phone numbers was counterbalanced across participants. The order of the two priority conditions was also counterbalanced, with the exception that the order in the second block mimicked the order in the first block. The experiment took about 75 minutes.

Dialing practice trials: To ensure that each number was memorized in accordance with the intended chunk structure, we controlled the learning process. For each of 10 learning trials, the number was presented on the simulator screen with all digits covered by an X, except for those from one chunk of digits (e.g., 07722-xxxxxx). Participants had to dial this chunk on the phone. As soon as a chunk was dialed, it was covered up and the next chunk was revealed (e.g., xxxxx-229944).

Single-task driving trials: In the single-task driving trials (30 seconds each) the objective was to keep the car close to lane center. Feedback on RMSE (root mean squared error) lateral deviation (i.e., drift from lane center) was given after

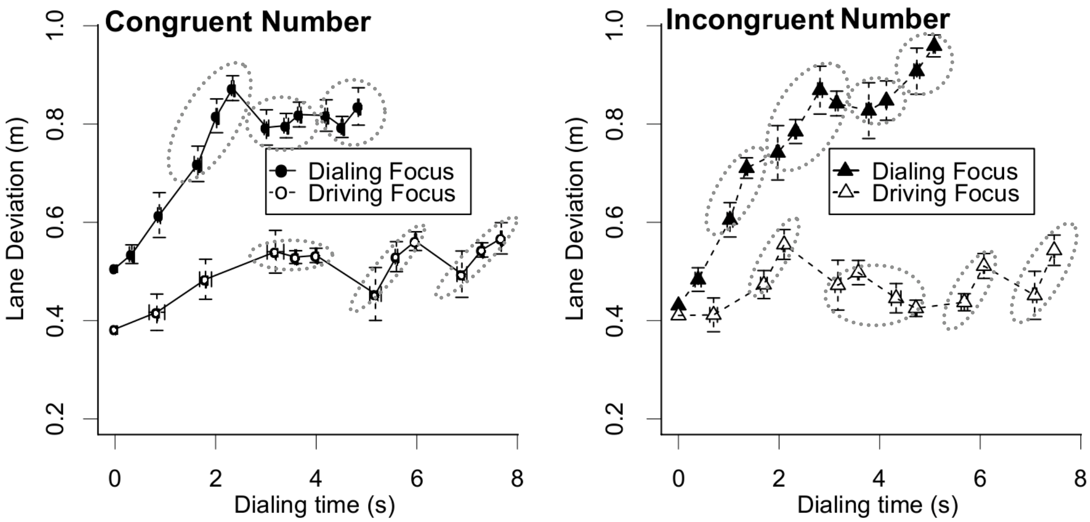


Figure 1: Time versus lateral deviation from lane center for the congruent number (#-07333-888111, left) and the incongruent number (#-07722-229944, right) in both the dialing focus (closed) and driving focus condition (open). Error bars represent standardized error. Dotted ellipses indicate a group of repeating digits.

each trial. Every fifth trial average performance was reported.

Single-task dialing trials: Participants were instructed to dial the phone number as fast as possible. Feedback was given on total dialing time (the time between the two presses of the '#' key). Every fifth trial average performance was reported.

Dual-task driving + dialing trials: Participants had to drive the simulated car and dial the phone number. They were instructed upfront to prioritize either safe driving over fast dialing (driving focus) or fast dialing over safer driving (dialing focus). In the driving focus condition, participants got feedback on RMSE lateral deviation, similar to the single-task driving trials. In the dialing focus condition, feedback was on dialing time, similar to single-task dialing trials. Trials were completed once the participant finished dialing the number, or after 60 seconds, whichever came first. Feedback on trial performance was given after each trial. Additional feedback on average performance was given every fifth trial.

RESULTS

The critical dual-task performance measures were dialing time (seconds), the RMSE lateral deviation of the vehicle from lane centre (meters), and active steering wheel movements. A trial was defined from the time of the initial press of the '#' key to the press of the last digit. A significance level of .05 is used throughout the paper.

Data from one participant were excluded because their mean dialing time (6.8 in pretest; 10.0 in dual-task) was greater than two standard deviations from the overall participant mean (pretest M = 4.4, SD = 0.5, and dual-task M = 6.3, SD = 0.8). We also excluded trials in which a dialing error was made (14.7% of trials).

Figure 1 shows the total dialing time and lateral deviation for both phone number conditions and both focus conditions. Each data point represents the timestamp at which either a '#' or a digit was pressed. It can be seen in the figure that when participants were instructed to focus on driving, they completed the dialing task more slowly, taking regular pauses in between digits to correct the heading of the vehicle. The net result was that the vehicle's lateral position remained relatively stable while dialing. In contrast, when participants were instructed to focus on dialing, they were faster at dialing, but the vehicle drifted farther from the lane center.

Statistical analysis using a 2x2 repeated measures ANOVA supports these observations. In terms of dialing task performance, it was found that dialing time was significantly faster in the dialing focus (M = 5.0, SD = 0.8) than in the driving focus trials (M = 7.6, SD = 1.6), $F(1, 10) = 30.02$, $p < .001$. In terms of driving performance, it was found that RMSE lateral deviation was smaller in the driving focus trials (M = 0.49, SD = 0.12) than in the dialing focus trials (M = 0.77, SD = 0.23), $F(1, 10) = 21.19$, $p < .001$. There was no significant effect of phone number on dialing time or RMSE lateral deviation, or a significant interaction. For comparison, baseline performance in single task was as follows. Dialing time was 4.4 (SD = 0.5). Average lateral deviation was 0.32 (SD = 0.08).

When did people choose to interleave?

Recall that the study was designed to test whether participants would use motor cues to signal when to switch between tasks. It is clear from Figure 1 that in the driving focus condition participants were regularly interleaving tasks to meet the performance objective of keeping the vehicle as close to the lane center as possible. Within Figure 1 sets of repeating digits are grouped using dotted ellipses. The figure seems to suggest that the points where lateral deviation was corrected corresponded with the positions at which the finger was repositioned. That is, lateral deviation seems to decrease more between groups of repeating digits than within groups of repeating digits (i.e., within the ellipses). We next consider steering movement data to determine if this is the case.

To infer periods of active steering control, we counted the number of steering movements in between two keypresses. A steering movement was identified from the raw data whenever there was a change in the steering wheel angle after at least three consecutive stable samples (at a frequency of 50 Hz).

We identified *breakpoints* (i.e., positions where dialing was suspended for driving) using this steering count data. In this analysis, the term *index* is used to refer to the position of a digit in a string of digits. For example, index five is the fifth digit in the string, and the steering count at index five indicates the number of steering movements made in between dialing the fourth and fifth digit.

Figure 2 shows the number of steering counts for both numbers in the dialing focus (left) and driving focus condition (right). As we might expect, there were more steering movements when participants focused on driving than when they focused on dialing. But more interestingly, it can be seen that there were more steering movements at positions where one number started a new series of repeating digits, while the other number continued a series of repeating digits.

Statistical analysis supported these observations. A 2 x 2 x 11 (focus x phone number x index) repeated measures ANOVA on steering count data found significant effects of focus, $F(1, 10) = 28.62$, $p < .001$, and index, $F(10, 100) = 13.89$, $p < .001$. While there was no significant effect of phone number ($p = .71$), there was a significant interaction between phone number and index, $F(10, 100) = 32.83$, $p < .001$. Planned follow-up tests of this interaction show that there was a significant simple effect ($p < .05$) of phone number for index positions 3, 4, 6, 8, 9, and 10, in both focus conditions. These positions are marked with a star in Figure 2.

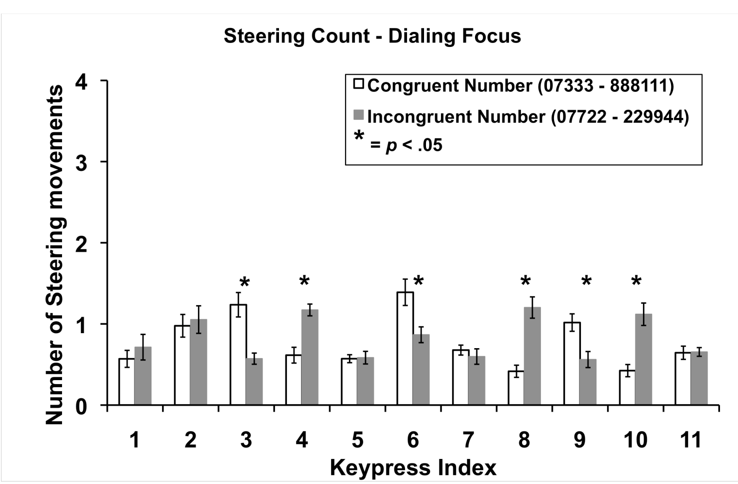
The steer count data at index 6 in Figure 2 offers an interesting comparison point across conditions. Here, both numbers had a chunk boundary, but only the congruent number had a change in digit – the incongruent number continued a series of repeating digits. That there was a significant difference in steering behavior at index 6 between the two number conditions is suggesting that participants were choosing to interleave at the chunk boundary when dialing the congruent number, but were choosing not to interleave at the chunk boundary when dialing the incongruent number.

GENERAL DISCUSSION

This paper investigated what cues people use to signal when to switch between tasks in a dual-task setting. We used a dialing while driving scenario as a case study. Results show that the relative priority given to each task overwhelmingly influenced how people choose to interleave attention between the tasks: When participants were instructed to give greater priority to the dialing task, they dialed the number quickly, but at a cost to driving performance. Conversely, when participants were instructed to prioritize the driving task, they interleaved the two tasks more frequently which meant that the dialing task took longer to complete. This dual-task performance trade-off is consistent with a larger body of work that has investigated multitasking performance (Navon & Gopher, 1979; Norman & Bobrow, 1975), and dual-task driving research (Brumby, et al., 2009; Horrey, et al., 2006; Janssen & Brumby, in press).

A novel finding from this work is that people are sensitive to motor cues when deciding when to switch attention between tasks: participants were found to perform corrective steering movements for the driving task in between repositioning the finger to a new key for the dialing task. In the incongruent number condition, where a set of repeating digits traversed across a chunk boundary, participants made at most minor corrections at the chunk boundary in the driving focus condition. Mostly participants kept on typing the digits until a set of repeating digits was completely keyed in. This contrasts with earlier work that found that people interleave dialing for driving at chunk boundaries (e.g., Brumby, et al., 2009; Salvucci, 2005). This contrasting finding could be explained by the fact that previous studies did not contain strong motor cues (i.e., no repeating digits) in the number, and contained two chunk boundaries instead of one. This made the effects of cognitive cues more prominent than in our study.

Our results suggest that motor constraints can take precedence over cognitive constraints in acting as a cue as to when to switch between tasks. That said, the data in Figure 2 suggests that cognitive cues are not completely overshadowed. For instance, if we consider how participants dialed the incongruent number in the driving focus condition, the number of steering movements at index 6 is increased relative to the neighboring indexes (but not relative to breakpoints). It might



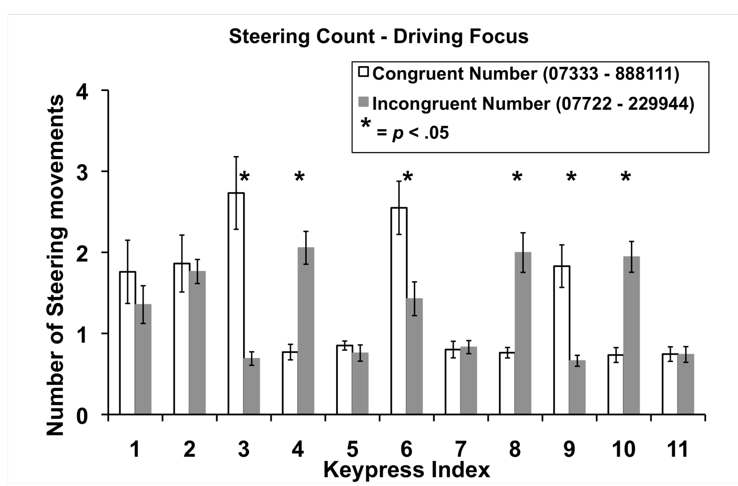


Figure 2: The number of steering movements made at each keypress index in the dialing focus (left) and driving focus (right) condition. Error bars represent standardized error. Bar color represents the two different number conditions. Stars indicate where the two numbers differ significantly. This is at positions where the first digit of a repeating set of digits is typed.

be that some occasional steering happens at the chunk boundary. However, this might also be an artifact of the algorithm used to detect steering counts: A steering movement was identified from the raw data whenever there was a change in the angle of the steering wheel after at least three consecutive stable samples (at a frequency of 50 Hz). If the number of required stable samples is altered, the absolute number of detected steering movements will alter: the smaller the required stable sample size, the larger the steer counts. Our current method is fairly robust against these fluctuations, as we looked at the contrast between the two phone numbers, given a constant algorithm for counting steering movements.

Although we argue that our findings reflect effects of memory and motor cues on performance, it is unclear whether these effects are directly caused by aspects of motor cues or by aspects of memory cues, as it is impossible to directly study the mental representation of the number in this task. For example, the breakpoints that occur between groups of digits might also be explained because repeating digits are memorized as one chunk (e.g., "three nines"). We assumed that there is only a chunk boundary between the fifth and the sixth digit of both phone numbers. Indeed, the relative delay in inter-keypress intervals at the chunk boundaries of both numbers (see Figure 1) supports this view (cf., Chase & Simon, 1973). Future work should make a more thorough distinction between effects of memory representation and motor cues.

Even when no distinction is made between effects caused by motor cues, and those caused by memory cues, an overarching claim can still be made. When people are given the choice about when to switch between tasks, they tend to switch at meaningful positions, but *only when this suits the task objective* (e.g., do they focus on dialing or driving?). A practical implication of this finding is that efforts on reducing the distracting effect of secondary task devices (e.g., cell phones, PDAs, navigation devices) by incorporating natural breakpoints in the task structure are worthwhile. For example, interfaces could be designed so as to require repeating motor actions at points where it is desirable to have continued engagement with the interface. At other points these action sets could be made short, so as to encourage task switching.

However, our results clearly show that the value of such design efforts would be dependent upon how the user decides to prioritize each of the tasks that they are performing. In a dialing while driving situation, it seems worthwhile to keep on promoting driver safety - if drivers set safety as their first priority they will be safer compared to situations where they are not, even if they are dual-tasking.

Suggestions for further investigation arising from the current study are two-fold. Firstly, the level at which the influence of motor cues on driving performance stops can be investigated. For example, is there a direct relationship between predicted Fitts' law index of difficulty (Fitts, 1954) and the positions of breakpoints?

A different strand of work would be to explore whether the strategies that the participants adopted fit a rational analysis (Anderson, 1990; Oaksford & Chater, 1998). Computational cognitive models could be used for this purpose. Already our findings are in line with some modeling predictions of dialing while driving tasks: Different strategies are used with different priorities(Brumby, et al., 2009; Janssen & Brumby, in press), and breakpoints are at meaningful positions (Salvucci, 2005).

CONCLUSION

This work contributes to a better understanding of the cues that people use to switch between tasks in a dual-task setting. When given the task to dial a phone number while driving, people can use motor preparation time as a cue to switch between tasks. The tendency to switch between tasks when repositioning the finger occurs even when cognitive cues favor interleaving at other positions. The cues are most effective when the priority of the driver is to drive as safe as possible. This implies that studies of side task performance while driving should incorporate explicit priority instructions. In addition, it highlights the importance of continuous promotion of driver safety.

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