# ATTENTIONAL DEMANDS OF DIFFERENT TYPES OF PDA TASKS

by

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Abstract

Personal Digital Assistants (PDAs) are mobile devices that offer a range of applications and are used in various environments (e.g., finding contact information driving while). These environments and applications vary on the level of attentional demands. The key interests of the present study were to explore the interference that occurs when both the PDA task and environment are highly attention demanding. The main goal of the present study was to investigate the attentional demands of two types of PDA tasks: Navigation and data entry.

Using a dual-task methodology, I conducted two experiments that explored the amount of attention (Experiment 1 and 2), and two experiments that investigated the types of attention (Experiment 3 and 4), required by the two PDA task types. For the first two experiments, a tone discrimination task was chosen as the secondary task as it has been shown to require general attentional resources. Participants first completed the tone discrimination task alone in order to assess performance in the baseline condition. In the test phase, participants completed a set of PDA tasks concurrently with a tone discrimination task.

To assess the type of attention required by PDA tasks, a method used to reveal the types of attention was first validated in Experiment 3. The validated method was used in Experiment 4. Participants completed a task that either drew on visuo-spatial resources or articulatory/auditory resources concurrently with either a PDA navigation or data entry task.

The two main findings of the 4 experiments were: Navigation requires more attention than data entry; data entry requires more articulatory/auditory resources while navigation requires both articulatory/auditory and visuo-spatial resources, but more of the latter.

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# Introduction

Personal Digital Assistants (PDAs) are mobile devices that are equipped with various applications and used in a wide range of environments. For example, these devices are used to look up route information to navigate around a city (Goodman, Gray, Khammampad & Brewster, 2004), to look up and access medical reference information (Embi, 2001), to write and send email messages, and to store contact information (e.g., a phone number). Some examples of environments in which these applications are used include a busy sidewalk, a quiet room, and a bright, sunny day on the beach.

The nature of the environments in which PDAs are used and the applications for which PDAs are used differ widely. One of the most important variables that distinguish between the various environments and applications is the attentional demands. Environments and applications differ with respect to their attentional demands. For example, a busy street is more attention demanding than a quiet room. Looking up a stored document in a directory is more attention demanding than pressing a button to turn off the device. The overall goal of this thesis was to learn about the interactions of the attentional demands between various environments and applications.

There are several possible combinations of environments and applications in relation to their level of attentional demands. First, both the environment and application can require little or no attention. One such example can be recording a simple voice message on a device while walking on a quiet street. The second combination occurs when either the environment or the PDA application is attention demanding. One of the examples is trying to type a formal email (i.e., high in attention demand) in a quiet room (i.e., low attention demand). The focus of this thesis is to explore the third combination,

when both the environment and application are highly attention demanding, for example, typing a formal email while walking on a busy sidewalk.

One of the factors that determine the level of attentional demands of an activity is the extent to which cognitive control is required to execute that activity. Schneider and Shriffin (1977) distinguished between two types of cognitive processes, automatic and controlled, that varies on the amount of attentional demands. Automatic processes require little or no attention. This is because the execution of the activity that relies on automatic processes draws on previously learnt responses. As a result, automatic processes can operate in combination with other activities that are attention demanding. Activities that rely on automatic processing require extensive training and practice. In contrast, controlled processes are initiated through effort and cognitive control. Due to the fact that these processes require substantial attention, they will interfere with other activities which also require controlled processing.

The interference observed while combining activities that are high in attentional demands points to a general limited capacity in attentional resources. Two different classes of attention theories have been proposed to explain variance in interference during multi-tasking: Single resource theories (Kahneman, 1973) and multiple resource theories (Parasuraman & Davies, 1984). Single resource theories propose that there is only one general reserve of attention that can be allocated amongst various concurrent tasks or activities. The extent of interference will depend in part on the load which each of the activities imposes and the allocation of attention among the activities (Moray, 1967). As the primary task demands more of these resources (i.e., becomes more difficult) fewer are available for a concurrent or secondary task, and performance on the latter task deteriorates accordingly. Primary-task workload would be inversely reflected

in secondary-task performance, depending on the allocation of attention toward the primary activity (Moray, 1967).

The multiple resource theory suggests that there is more than one resource for processing information. One of the most well-known multiple resource theories was formulated by Baddeley and Hitch (1974). They proposed a tripartite system that involves an attentional controller (central executive) assisted by two slave systems: The visuo-spatial sketchpad and the phonological loop. The central executive is responsible for coordinating information from the slave systems. The central executive is assumed to function like an attentional system that selects and operate control processes and strategies. The visuo-spatial sketchpad is used to hold and manipulate visual images. The phonological loop is used to hold and manipulate speech-related information. According to this theory, two activities that require the same types of attention would show task interference. That is, there should be observable decrements in performance on an activity executed singly compared to tending that activity with a second activity that also requires the same resources.

Interference between the environment and applications can also arise when there is competition for the same sensory/perceptual processes. An example includes trying to find a phone number (i.e., application) while driving (i.e., environment). Both activities demand the visual modality and thus it is necessary to switch between the two activities in order to handle both tasks concurrently. In other words, the efficiency of performing both activities is limited at the speed in which vision can be switched between the two activities. The limits of attending to both activities are restricted at the visual level of processing. There is a large area of research that investigates the interference that occurs due to competition for the same sensory/perceptual processes

(Broadbent 1957, 1958). However, this area is not of interest to the present thesis and will not be discussed further.

**Previous Research**

Prior research on attention and technology use has generally focused on exploring the effects of individual differences in attention on technology usability. For example, design guidelines are generally targeted towards accommodating individuals with reduced attentional capacity, such as older adults (Connelly & Hasher, 1993; Kotary & Hoyer, 1995). Morris and Venkatesh (2000) noted that large amounts of information are usually presented on small displays (e.g., mobile devices), and that could be problematic for older adults who have difficulties in handling a lot of information at the same time and sorting out task relevant information. They suggested that interfaces with reduced information content make it easier to focus attention on relevant information and reduce the time spent on information search. Aid in focusing attention can be provided by structuring the information, providing spatial and temporal cues, and manipulating the screen layout. Guidelines of interface design have also included recommendations to exclude graphic details that may be decorative to prevent distraction (Hawthorne, 2000).

Individual differences in certain cognitive abilities have been shown to be related to information search performance on a wide range of technologies. Several studies have found that individuals with lower spatial ability and poorer vocabulary skills take longer to retrieve information from a hierarchical database on a computer (Freudenthal, 2001; Vincente, Hayes & Williges, 1987). This effect due to spatial ability was prominent even after taking into account prior experience with technology (Vincente, Hayes & Williges, 1987). Individuals with poorer spatial ability performed less efficient searches on a cell phone (Ziefle & Bay, 2004). On searching for information from the World Wide

Web, individuals with poorer spatial ability took longer to find the relevant information (Dahlbäck, Höök & Sjölinder, 1996). Lower mental rotation, verbal and visual memory performance was linked to greater time spent on the task in virtual reality navigation (Moffat, Zonderman & Resnick, 2001).

Data entry performance on a full-sized keyboard has been linked with basic cognitive abilities in a study by Czaja and Sharit (1998). Age, processing speed, motor skills, visuo-spatial skills and prior computer experience have been found to have an impact on entering data into records or search fields. Among these factors, visuo-motor skills and memory predicted the number of typing errors above and beyond prior experience with computers.

In a recent study (Li and Graf, 2007), certain cognitive abilities were found to predict data entry performance on a PDA. Among sensory abilities, episodic memory, perceptuo-motor skills, and verbal intelligence, we found that sensory abilities and episodic memory were the stronger predictors for different types of data entry errors on a PDA. The finding that verbal intelligence had no predictive power is not surprising in view of the fact that none of the data entry tasks were designed to challenge verbal skills or to require extensive language processing.

**Objectives and Motivations**

The motivation for this research was to learn more about the factors that influence the usability of PDAs in order to increase the usability of these devices. The majority of research and design guidelines have focused on providing support for individuals with poorer cognitive abilities. However, the usability of technologies can be compromised even for individuals with relatively better cognitive abilities in certain situations. If the application is inherently very attention demanding, then usability is reduced when these applications are used in environments that are also attention

demanding, for example, recording a complex voice message while driving in busy traffic. Moreover, if both the environment and application demand the same type of attention, then usability can also be compromised. As a first step to understanding the interference that might be produced in these situations, one of the objectives of this thesis is to learn more about whether certain PDA tasks are more attention demanding than others, and about the type of attention that they require.

The second motivation for this research was to examine the relationship between attention and PDA usability in order to guide design specifications for these devices to be more suitable for the various environmental demands. While it has certainly been inferred that attention plays a crucial role in the usability of technology (Hawthorn, 2000), there have been few studies that empirically demonstrated a link between attention and usability. In addition, while there is a plethora of design guidelines on designing websites, cell phone menus, and interfaces of various software applications and computer systems, the guidelines may not be applicable to PDAs. PDAs generally have different sized screens and rely on a different interaction technique (i.e., touchscreen using stylus). Thus, I believe that is also important to generate empirical data that serves as a start for basing design guidelines for PDAs.

**Contributions**

This type of research serves to identify whether future research needs to be focused on reducing the attentional demands of certain types of PDA tasks in order to maximize the effective and efficient use of these devices. One of the limitations of previous studies is that they often only report either the completion time (an index of efficiency), or number of errors (an index of efficacy). Thus, it is difficult to ascertain whether the individuals experienced a speed-accuracy trade-off. In addition, the studies that reported the number of committed errors are expressed as absolute values. As a

result, it is difficult to interpret whether the error presses were considered high or low in relation to the total number of presses. Moreover, the criteria used to classify errors were unclear. The experiments in this thesis addressed the three limitations mentioned earlier. The experiments used clearly developed criteria to categorized errors, used standardized methods to calculate the data, and reported indexes of both efficiency and effectiveness.

This research developed and validated a dual-task methodology to assess the attentional demands of technology use. While this methodology has been used in a variety of human factor studies (see Wickens, 1992 for a review) and memory studies (Craik, Govoni, Naveh-Benjamin & Anderson, 1996; Fernandes & Moscovitch, 2000; Naveh-Benjamin, Craik, Guez, Dori, 1998), this method has not yet been applied to specifically assess the attentional demands of PDA tasks.

The design of the secondary task must meet several criteria. First, the secondary task must be designed to assess interference produced by the attentional demands of the PDA tasks, and not interference produced by competition of the same perceptual processes of the PDA tasks. Second, the secondary task must include measurable performance variables. Once validated, this method can also be used to assess the attentional demands of other technological devices, such as cell phones, mp3 players, and applications on personal computers.

**Overview**

The overall goal of this thesis is to understand the attentional demands of PDA tasks. While there are many applications that can be used on a PDA, the majority can be classified in one of two types of tasks: Navigation and data entry. Navigation refers to locating a certain file, folder or device information through the menu options. Data

entry refers to entering data (i.e., a specific phrase or numbers) via a touch-screen keyboard using a stylus.

The dual-task methodology was used as the general set-up for measuring the attentional demands of performing PDA tasks. The methodology involves having an individual perform two tasks concurrently (i.e., divided attention condition), and to measure task interference relative to single-task performance (i.e., full attention condition). In my experiments, the PDA tasks were always designated as the primary task. Therefore, changes in secondary task performance were attributed to the reduced availability of attention due to allocation of attentional resources to the PDA tasks.

For experiment 1 and 2, I chose tone discrimination as the secondary task since this task has been shown to involve the central executive (Klauer & Stegmaier, 1997). The second reason is that this task was designed to avoid the same perceptual processes used by the PDA tasks (i.e., auditory and vocal for tone discrimination; motor and vision for PDA tasks). This arrangement ensured that the tone discrimination task assessed the attentional demands of PDA tasks, as opposed to interference produced by competition for the same modalities. Third, the tone discrimination task offered observable performance variables which could be measured objectively, which allowed comparisons of any changes in performance when tone discrimination was performed with the PDA tasks.

I designed and conducted two experiments to explore whether data entry and navigation tasks require different amounts of attention. In Experiment 1, the secondary objective was to adapt the dual-task methodology to explore the attentional demands of the PDA tasks. Participants were asked to first perform the tone discrimination task alone to get a baseline assessment, followed by performing a series of navigation or data entry tasks concurrently with the tone discrimination task.

Following up on the findings from Experiment 1, Experiment 2 was designed to determine whether the results obtained in Experiment 1 were due to attentional demands or due to the difficulty of switching between the tone discrimination task and PDA tasks. Participants first completed an easy and hard version of the tone discrimination task in the baseline condition. In the test conditions, participants completed the easy and hard version of the tone discrimination task with either a set of data entry and navigation tasks on the PDA.

Experiment 3 and 4 were designed and conducted to explore whether performing the data entry and navigation tasks require different types of attention. The primary objective of Experiment 3 was to confirm that a method developed by Brooks (1968) is valid and reliable for revealing the types of attention, specifically visuo-spatial and auditory/articulatory attention. The same tasks, a task that draws on visuo-spatial resources and a task that requires articulatory/auditory resources, described in the original study were used.

For Experiment 4, the method validated in Experiment 3 was employed to assess the types of attention required by the PDA tasks. Participants performed concurrently either a navigation or data entry task with one of the two tasks that require different types of attention described in Experiment 3.

## Experiment 1

The primary objective of this study was to explore the attentional demands of two PDA task types: Navigation and data entry. A dual-task methodology was used to assess the attentional demands of each type of task. While the dual-task methodology has been used successfully in other areas of research, it has been never been employed for assessing the attentional demands of PDA tasks. Thus, an additional objective of the present study was to adapt the dual-task methodology to the exploration of the attentional demands of PDA tasks.

### Method

#### Participants

Twenty-six undergraduate students were recruited through the subject pool in the psychology department at the University of British Columbia. They were compensated with one course credit in return for their participation. The experiment was conducted with the approval of the University of British Columbia behavioral ethics review board.

#### Apparatus

An unmodified Hewlett-Packard iPAQ rx3715 handheld computer was used for this experiment [see Figure 1]. This device has a color screen which is 2.26 inches wide and 3.02 inches high. As shown in Figure 1, five hardware buttons are positioned below the screen. The button in the middle is a navigation key. The four other buttons are designed for accessing different applications and PDA status information. To interact with the device, users either press these buttons or use a stylus to select icons or menu options on the screen. Data entry is done via a touch screen QWERTY keyboard using a stylus. On this screen, each letter, digit or symbol has a 'target area' (i.e. the area for selecting each letter) that measures 4 mm in width and 3 mm in height.

Figure 1

**Materials**

The stimuli for the tone discrimination task were pure tones, each exactly 100 ms in duration. One tone, herein called the standard tone, had a frequency of 4000 Hz. The other tones required for this task, called odd or target tones, had frequencies of 4020 Hz, 4040 Hz, 4060 Hz, 4080 Hz, 4100 Hz, 4120 Hz, 4140 Hz, 4160 Hz or 4180 Hz. All tones were created using Audacity v.1.2.6, a freeware Cross-Platform Sound Editor (Mazzoni & Dannenberg, 2000). Each tone was stored as a .wav file, with single channel 16-bit PCM coding at a sampling rate of 44.1 kHz.

**Tone Discrimination Task**

Stimulus presentation and response recording for the tone discrimination task were controlled by a PC, using the EPrime v.1.0 software (Psychology Software Tools Inc., Pittsburg, PA). Participants wore headphones to ensure controlled presentation of the tones. The volume of the tones was set at a level which each individual considered to be "comfortable".

For the tone discrimination task, participants listened to a series of standard tones interspersed with target tones. I instructed participants to say the word 'fruit' into the microphone each time they heard a target tone (i.e., a tone higher in pitch than the standard tone). This response word (i.e., fruit) was chosen to ensure that the microphone captured the onset of the vocal response. Participants were instructed to make their responses as accurately and as quickly as possible.

The tone discrimination task consisted of nine blocks, each with 150 trials. The target tones varied across blocks while the standard tone remained constant. During each trial, a tone was presented followed by a random inter-stimulus interval (ISI) of 500 ms, 1000 ms, 1500 ms, 2000 ms, 2500 ms or 3000 ms (the ISI following a target tone

was always 1500 ms in duration to ensure an adequate amount of time for responding). The first three trials in each block always involved the presentation of a standard tone in order to "habituate" participants to this sound. In the remaining 147 trials, participants were presented with either a standard or target tone. On each set of thirteen trials, two trials were randomly selected to present a target tone.

**PDA Tasks**

Six common PDA tasks were selected. Three tasks required searching through the menu layers to find information (check the battery, retrieve appointments and find a picture), and 3 tasks required entering data (enter contact information, enter expense information, and make an appointment). Each of these tasks can be completed in a number of different ways. Table 1 shows the number of steps required for completing each task in the most efficient or optimal manner.

Table 1

**Check the battery.** The instructions for this task directed participants to find the current status of the PDA battery and to report the remaining battery charge.

**Retrieve appointments.** For this task, participants were required to find and report to the experimenter all appointments scheduled for 7 weeks away from the current date.

**Find a picture.** Participants were instructed to find a picture of a green door in the personal folder.

**Enter contact information.** For this task, participants were required to find the contacts function, and to enter contact information for a laboratory, including the name, the complete address, as well as the phone number and the email address of that laboratory.

**Enter expense information.** Participants were required to find the Excel workbook and enter a series of numbers into designated cells.

**Make an appointment.** This task required finding the date 6 weeks away from the current date in the calendar, entering a restaurant name for an appointment at noontime, and setting a reminder to go off one hour prior to this event.

**Neuropsychological Tests**

A neuropsychological test battery was employed to assess participants' cognitive abilities. The battery was comprised of four standardized tests: the Digit Symbol Substitution Test (Wechsler, 1981), the North American Adult Reading Test (Blair & Spreen, 1989), the Reverse Digit Span Test (Wechsler, 1981), and the Trail Making Test (Reitan, 1992). I administered each neuropsychological test according to the instructions in the published manuals. The results of these tests are not directly pertinent to the objectives of the present project and thus will not be reported or discussed here.

**Design**

This experiment included a baseline condition and two critical test conditions identified, respectively, as the data entry and navigation condition. In the baseline condition, participants completed the tone discrimination task alone, while in the critical test conditions, they completed this task concurrently with a PDA task. The baseline condition was required in order to find a difficulty level where tone discrimination accuracy was approximately 80% for each participant. This accuracy level was selected because it reflects performance that is off the ceiling, while leaving sufficient down-side room for revealing the additional resource demands of the concurrent PDA tasks which had to be completed in the data entry and navigation condition. Each participant completed the same set of PDA tasks, which are listed in Table 1.

## Procedures

I tested participants individually in a session that lasted approximately 60 minutes. Upon obtaining their written consent, I administered the tasks in the order described below.

Each participant first completed the tone discrimination task alone in the baseline condition in order to find a frequency difference between the standard and target tone at which a level of accuracy of approximately 80% would be achieved. In order to find this level, I used a calibration procedure in which the frequency of the target tone was reduced by 20 Hz (i.e., the difference between the target tone and the standard tone was decreased) across successive blocks of trials. Specifically, for the first block of trials, the target tone frequency was 4100 Hz. If performance accuracy was above 80% after 150 trials, I reduced the target tone frequency by 20 Hz for the next block of 150 trials. I continued with this calibration procedure until the participant's performance was approximately at 80%.

In the next phase of the experiment, participants completed the tone discrimination task together with the PDA tasks in the order listed in Table 1. I instructed participants to focus on completing the PDA tasks accurately and quickly, but to respond to the target tones whenever possible. For each of the PDA tasks, I explained to participants about the goal of the task. For the navigation tasks, participants were given written instructions about the goal of the task. For the data entry tasks, participants were provided with the to-be entered information in written form. Participants were free to refer to the instruction sheet at any time during the task. At any time in the course of any of the tasks, participants were permitted to ask for help, for hints or information about how to proceed.

The frequency difference between the standard and target tone which was obtained for each subject in the baseline condition was used for the tone discrimination task when it had to be performed in conjunction with one of the data entry or navigation tasks in the critical test conditions. I started the tone discrimination task when participants began each PDA task and terminated the task as soon as the PDA task was completed.

A Hitachi DZ-MV380A digital video camera was used to create a complete record of participants' button-presses and stylus interactions with the PDA from the start (i.e., turning the PDA on) to the end (i.e., turning the PDA off) of each PDA task for offline coding. I started the video recording immediately before participants turned the PDA on and stopped the video recording immediately after participants completed the task and turned the PDA off.

Following the completion of the PDA tasks, I administered the battery of neuropsychological tests. After the last neuropsychological test was completed, participants were given a verbal debriefing, as well as a debriefing form, and course credit.

## Results

### Data Preparation

For the PDA tasks, I developed a detailed manual with step-by-step instructions for scoring each interaction (e.g., button-press, stylus-click) with the PDA, as well as for scoring participant-experimenter interactions (e.g., requests for help). The manual was developed based on the guidelines and definitions from a manual in a previous usability study (Graf & Li, 2007). For the manual in the previous study, an iterative method was used for developing the scoring manual, alternating between writing scoring instructions and applying those instructions, until the manual could be used reliably by one other

coder. Two independent coders scored the complete video record of 10 different subjects. The reliability was .80 and above across the 9 different PDA tasks.

Participants' performance of the PDA tasks was coded using the video records. I watched the videos that captured participants' interaction with the PDA, and for each task I counted the number of presses, as well as recorded the amount of time to complete each task. For navigation tasks, a press was scored as incorrect when it displayed an undesired screen (i.e., did not lead towards the completion of the task) or when it produced no change in the screen. Correct presses yielded the display of a desired screen, one that was required to progress towards completing the task. Completion time for navigation tasks was calculated by the amount of time elapsed from the start to the end of the task. The start of a navigation task was defined by the first time the stylus touched the screen; the end was defined by the display of the target screen (i.e., the information to be found). I calculated data entry errors using a method developed by Wobbrock and Myers (2006). Data entry error rate was expressed as a function of uncorrected and corrected errors by the final entered data. The standardized metric words per minute (WPM) was used as an indication of data entry speed. I calculated data entry speed by dividing the total number of presses by the completion time in minutes to compute the characters per minute (CPM) metric. Then, I computed WPM by dividing CPM by five. These methods were chosen as it allowed comparisons across studies using the same metrics.

The results from the tone discrimination task and PDA tasks were screened for outliers, defined as falling more than three standard deviations away from the sample mean. One outlier was found. The outlier was replaced with a non-outlying value, a number that was three standard deviations above the sample mean.

For each participant, I calculated the mean percentage of correct and incorrect identifications of target tones, adjusted identification of target tones and the median response time (RT) for the correct and incorrect responses in each condition of the experiment (baseline, data entry, navigation) for the tone discrimination task. A correct identification was scored when a participant made a response to a target tone, while an incorrect identification was scored when a participant made a response to a standard tone. The adjusted identification score was computed by subtracting the percentage of incorrect identifications by the percentage of correct identifications. Three participants did not make any correct responses on the tone discrimination task while they were concurrently performing either the data entry or navigation tasks. The data for these three participants were excluded from the analysis. The analysis was conducted with data from the remaining 23 participants.

**PDA Tasks**

The dependent measures for the PDA tasks were the percentage of correct presses, the percentage of errors in the data entry and navigation tasks, speed of data entry, and the amount of time to complete navigation tasks.

The average percentage of correct presses in navigation across the tasks was 56.58% (*SD* = 10.90). Overall, 38.83% (*SD* = 14.16) of the total presses was categorized as incorrect in navigation. Among the navigation tasks, participants made the greatest percentage of errors while trying to find the page for entering contact information (*M* = 58.31, *SD* = 21.53), followed by trying to find the battery (*M* = 47.27, *SD* = 24.90), trying to find the correct date to make an appointment (*M* = 44.71, *SD* = 28.62), trying to retrieve the appointment dates (*M* = 29.87, *SD* = 25.58) and finding a picture (*M* = 36.97, *SD* = 30.01). Finally, participants made the least percentage of errors trying to find the Excel program to enter information (*M* = 15.83, *SD* = 22.19).

The average percentage of correct presses in navigation across the tasks was 77.71% (*SD* = 5.71). Of the total presses made during data entry, 6.60% (*SD* = .03) were errors. In general, the percentage of errors for each data entry task was low. Participants made the smallest percentage of errors while entering information in the Excel sheet (*M* = 4.80, *SD* = 5.73), followed by entering contact information (*M* = 7.21, *SD* = 3.07), and entering appointment information (*M* = 7.80, *SD* = 3.00).

A paired samples *t*-test was conducted using the average percentage of navigation and data entry tasks errors. The results revealed that participants made a significantly greater percentage of errors when performing navigation tasks compared to data entry tasks, $t(22) = 11.39$, $p < .001$.

Average completion time for the navigation tasks was 32.15 s (*SD* = 14.43). Finding the battery (*M* = 48.30, *SD* = 27.16) took the longest, followed by finding the contacts page for entering information (*M* = 41.05, *SD* = 33.09) and finding the correct date for entering appointment information (*M* = 41.65, *SD* = 29.09). Finding the appointment date took 30.61 seconds (*SD* = 29.78), followed by finding the picture (*M* = 23.04, *SD* = 21.40), and finding the Excel sheet (*M* = 8.22, *SD* = 6.84).

Mean data entry speed for the data entry tasks was 11.31 WPM (*SD* = 2.28). Data entry speed was the quickest for entering appointment information (*M* = 14.93, *SD* = 4.43), followed by entering contact information (*M* = 10.08, *SD* = 4.85), and entering information in an Excel sheet (*M* = 8.91, *SD* = 1.60).

**Tone Discrimination Task**

The purpose of this experiment was to explore how performance changed when the tone discrimination task was performed alone versus in conjunction with a PDA task. The dependent measures for the tone discrimination task, in each task condition, were

the percentage of correct, incorrect, and adjusted identifications of target tones, and the time required to make correct identifications.

Table 2 shows the mean percentage of correct, incorrect, and adjusted identifications of target tones, as well as the 95% confidence intervals, for each condition. Compared to the Baseline condition, performance was lower in both the Data Entry and Navigation condition, but this effect was greater in the Navigation condition. Participants made a similar percentage of incorrect identifications in the Baseline and Navigation condition. Participants made approximately 1/3 fewer incorrect identifications in the Data Entry condition.

Table 2

In order to take into account the effect of differences in incorrect identifications on the pattern of correct identifications, the adjusted identifications were explored in detail. The average values of adjusted identifications for the baseline, data entry, and navigation conditions followed the same pattern as correct identifications. The mean value in the data entry and navigation condition was not encompassed by the 95% confidence interval of the baseline condition, indicating that performance accuracy was significantly lower in both the data entry and navigation conditions compared to the baseline condition. Similarly, the 95% confidence interval of the data entry condition does not include the mean value of the navigation condition, indicating that accuracy was significantly lower than performance accuracy in the data entry condition. A large effect size was found for the percentage of correct identifications across conditions, $f$ = 2.31.

Since the pattern of results did not change even when taking into account the incorrect identifications data, only the median response times for correct identifications were explored. Figure 2 shows the response time (mean of medians) for correct

identification of target tones, as well as the 95% confidence intervals, in each condition. The summarized results revealed increased response times for both the data entry and navigation conditions compared to the baseline condition. The mean response times in the data entry and navigation conditions were not encompassed by the 95% confidence interval of the baseline condition, indicating that response time was significantly greater in the test conditions. Response times were not significantly different across the Data Entry and Navigation conditions. A large effect size was found for the response times across conditions, $f = 0.96$.

Figure 2

**Discussion**

For this experiment, I developed a version of the dual-task methodology to explore the attentional demands of navigation and data entry tasks. I had participants perform a tone discrimination task in the baseline condition in order to find a difficulty level that would yield accuracy performance at approximately 80%. Next, participants performed the tone discrimination task with either a data entry or navigation task.

Performance for both the data entry and navigation tasks was poorer than what was found in previous studies. In particular, data entry errors were slightly greater and typing speed was slower compared to studies where participants performed data entry using a QWERTY keyboard on a PDA. Zha and Sears (2001) reported 4% (12.62 WPM) and 5% error rate (6.98 WPM) for two data entry tasks. Fleetwood et al. (2002) found that experts enter uncorrected text (i.e., where erasing errors were not permitted) at a rate of 17.91 WPM and novices enter at a rate of 15.38 WPM with a 2% error rate for both groups. For navigation tasks, participants took longer to find the information and made a greater percentage of errors compared to the findings in a recent usability study with a PDA (Graf & Li, 2007).

The poorer PDA task performance found in this experiment is likely due to distraction of concurrently attending to the tone discrimination task. Attending to a second task may have distracted participants from performing the PDA tasks as well as they could when they performed these PDA tasks alone. However, the results obtained in this experiment were only slightly poorer compared to findings obtained in previous studies (Graf & Li, 2007; Fleetwood et al., 2002; Zha & Sears, 2001) when full attention was available (i.e., when the PDA tasks were completed alone). The findings from this experiment suggest that participants focused on completing the PDA tasks as well as possible.

The results from the tone discrimination task are consistent with findings from previous studies that also found secondary task costs when participants were required to perform two tasks concurrently (e.g., Troyer, Winocur, Craik & Moscovitch, 1999; Anderson, Iidaka, Cabeza, Kapur, McIntosh & Craik, 2000). The comparable findings indicate that a dual-task methodology using tone discrimination is valid for assessing the attentional demands of PDA tasks.

Secondary task costs obtained in this study were slightly larger than what was found in previous research that used auditory discrimination as a secondary task. In a study involving the effects of divided attention on encoding and retrieval, Iidaka, Anderson, Kapur, Cabeza and Craik (2000) reported the percentage of words recalled when encoding performed alone was 79%. The percentage of correct words recalled dropped to 58% when encoding was done with a tone discrimination task (magnitude change of 26.58%). This finding suggested that performing tone discrimination is attention demanding. Klingberg and Roland (1997) reported a 15.66% change in response time to detect a pitch change in a series of presented tones when combined with a visual detection task.

The greater secondary task costs obtained in this experiment compared to previous studies (Iidaka, Anderson, Kapur, Cabeza & Craik, 2000; Klingberg & Roland, 1997) is likely due to the greater attentional demands required by PDA tasks. The finding that tone discrimination performance was affected to a greater extent by navigation tasks than by data entry tasks suggest that navigation is more attention demanding than data entry. Response times for adjusted identifications did not significantly differ for the Data Entry and Navigation conditions. The null difference suggests that the difference in the percentage of adjusted identifications in the data entry and navigation conditions was not due to simply placing more attention while performing data entry tasks compared to navigation tasks.

One of the common criticisms of using a dual-task methodology to assess attention is that the results can be explained either by attention or task switching. In task switching, individuals who perform two concurrent tasks allocate their attention to only one task at a time. To attend to the second task, individuals need to disengage from the current task and re-allocate their attention the second task. In order to attend to the first task again, individuals need to re-allocate their attention back to the first task. According to task switching, it is possible that participants find it more difficult to switch between navigation and tone discrimination compared to data entry and tone discrimination. Thus lower accuracy performance in the Navigation condition could also be explained by task switching. The second study was carried out to investigate whether the findings in Experiment 1 were due to task switching or attention.

## Experiment 2

Experiment 2 was designed to investigate whether the dual-task methodology used in Experiment 1 assessed the attentional demands of different kinds of PDA tasks, the difficulty of switching between the PDA tasks and tone discrimination task, or a combination of the two factors. The general design of Experiment 2 was the same as for Experiment 1. An additional factor of the tone discrimination task, easy and hard was included in this experiment. The additional factor permitted manipulation of the required attentional resources to perform the tone discrimination task; more attention is required for the hard version compared to the easy version.

I expected that, as in Experiment 1, adjusted identifications in the tone discrimination task would be lower when performed together with navigation tasks than data entry tasks. If navigation requires more attention than data entry, then the differences in the percentages of adjusted identifications between the hard and easy tone discrimination task would be greater among navigation tasks than among data entry tasks. Concurrently performing a navigation task and hard tone discrimination task should be the most attention demanding, and the percentage of adjusted identifications should be the lowest in this condition. Since an easy tone discrimination task requires less attention, the percentage of adjusted identifications should also be lower, but to a lesser extent compared to a hard version of the tone discrimination task. In contrast, since data entry tasks require less attention, there is more leftover attention to perform the tone discrimination task. The percentage of adjusted identifications should be similar while performing either an easy or hard tone discrimination task.

On the other hand, if the dual-task methodology which uses tone discrimination is sensitive to task switching, then switching between a navigation task and tone discrimination should be equally difficult should be more difficult than switching between

a data entry task and tone discrimination. In addition, switching between a tone discrimination task (easy or hard) and a PDA task (data entry or navigation) would be equally difficult. Thus, I expected that, similar to Experiment 1, the overall the percentage of adjusted identifications would be lower when the tone discrimination task was combined with navigation tasks compared to data entry tasks. In addition, I expected that the difference in the percentage of adjusted identifications would be similar between an easy and hard tone discrimination task when combined with navigation tasks. Lastly, I expected that he difference in the percentage of adjusted identifications would be similar between an easy and hard tone discrimination task when combined with data entry tasks.

## Method

### Participants

Thirty undergraduate students were recruited through the subject pool at the Psychology department in the University of British Columbia. They participated individually in this one session study lasting approximately 60 minutes. They were compensated with one course credit in return for their participation. The experiment was conducted with the approval of the University of British Columbia behavioral ethical review board.

### Apparatus

The same device as in Experiment 1 was used.

### Tone Discrimination Task

The materials, design and instructions for the tone discrimination task were the same as for Experiment 1, except for the duration of the ISI. The interval from the onset of one tone to the onset of the next was narrowed to 600ms, 1100ms, and 1600ms.

From the results Experiment 1, the mean of median response time was no greater than 1200 ms. Thus, the ISI was reduced since the extra time was not needed.

**PDA Tasks**

Twelve tasks commonly performed on a PDA were selected for this study. A greater number of tasks were included for this experiment so that there were three PDA tasks in each condition that involved a PDA task. This number of PDA tasks per condition was chosen to obtain an appropriate sample of PDA task performance. Six tasks required participants to navigate through the menus: Find a picture, retrieve appointments, check the battery, find a voice recording, find an email address, and find owner information. The other 6 tasks required participant to enter text on a QWERTY keyboard using a stylus: Enter sentences, name new folder, enter contact information, enter email message, enter appointment information, and enter expense information. Six of the twelve tasks were identical to the ones used in Experiment 1. The newly added tasks in Experiment 2 will be described below. Each of these tasks can be completed in a number of different ways. Table 3 shows the number of number of steps required for completing each task in the most efficient or optimal manner.

Table 3

**Find a voice recording.** For this task, participants were required to locate the folder named 'Personal' and to play the voice message named 'recording'.

**Find an email address.** Participants were instructed to find, and display on the screen, the email address for the contact 'Aphasia project'.

**Find the owner.** For this task, participants were required to search through several menus to find the screen that showed the name of the device owner.

**Enter sentences.** Participants were instructed to enter two sentences into a Word document.

**Enter an email message.** This task required participants to enter a brief message into the email composer in the device.

**Name a new folder.** Participants were required to create a new folder and name it 'Experiment results'.

**Design**

The design of this experiment was a 2 x 2 factorial with tone discrimination difficulty (easy, hard) and task condition (baseline, data entry, navigation) manipulated as within subjects factors. The baseline condition was included in order to find two difficulty levels where accuracy was approximately 80% for the easy tone discrimination condition and approximately 70% for the hard tone discrimination condition for each participant. These accuracy levels were selected because they reflect performance that is off the ceiling, while leaving sufficient down-side room for revealing the additional resource demands of the concurrent PDA tasks which had to be completed in the data entry and navigation condition.

**Procedures**

I tested participants individually in a session that lasted approximately 60 minutes. Upon obtaining their written consent, I administered the tasks in the order described below.

Each participant first completed the tone discrimination task alone in the baseline condition in order to find a frequency difference between the standard and target tone at which a level of accuracy was approximately 80% and 70%. These performance levels were identified by means of the same calibration procedure as in Experiment 1.

In the next phase of the experiment, participants completed either an easy or hard tone discrimination task together with the PDA tasks listed in Table 3. Each participant completed the same set of PDA tasks in combination with a tone

discrimination task. Presentation of the four conditions (PDA task type by tone discrimination task difficulty) was counterbalanced by means of a Latin Square design.

The instructions for performing a PDA task concurrently with a tone discrimination task were the same as in Experiment 1.

The procedures for starting and ending the tone discrimination task, as well as procedures for recording PDA task performance, were the same as in Experiment 1.

After the last PDA task was completed, participants were given a verbal debriefing, as well as a debriefing form, and course credit.

## Results

### Data Preparation

The coding manual for the PDA tasks was developed in the same way as in Experiment 1. The methods for coding PDA task performance and calculating tone discrimination task performance were same as in Experiment 1.

All data were checked and corrected for transcription and coding errors until accuracy was greater than 99%. The results from the tone discrimination task and PDA tasks were screened for outliers, defined as falling more than three standard deviations away from the sample mean. There were two outliers discovered in the tone discrimination task and 1 outlier in the PDA tasks. Each outlier was replaced with a number either 3 standard deviations above or below the sample mean, respectively.

Six participants did not make any correct identification on the tone discrimination task while concurrently completing a PDA task. Data from these participants were excluded from the analyses. The data from the remaining 24 participants were included for the analyses. There were five missing values in the PDA tasks. Each value was replaced with the average value from that variable.

**PDA Tasks**

The dependent measures for the PDA tasks were the percentage of correct presses, the percentage of errors in the data entry and navigation tasks, speed of data entry, and the amount of time to complete navigation tasks.

Overall, two-thirds of the presses (*M* = 66.23) in the navigation tasks were correct. An in depth examination of the navigation errors by each task reveals that the percentage of errors ranged from 8.15% to 49.15%. Nearly half of the total presses while finding the battery were errors (*M* = 49.15, *SD* = 23.51). Other tasks had slightly fewer errors, such as finding the page for renaming the folder (*M* = 42.67, *SD* = 19.36), followed by finding a voice recording (*M* = 43.38, *SD* = 20.00), finding appointments (*M* = 32.52, *SD* = 21.85), creating a new document in Word (*M* = 28.00, *SD* = 31.27), creating a new email message (*M* = 32.94, *SD* = 29.79), finding the appropriate date for entering information (*M* = 31.46, *SD* = 19.80), creating a new contact (*M* = 23.46, *SD* = 28.70), finding an email message (*M* = 23.29, *SD* = 27.58), and finding the page that displays the owner of the device (*M* = 22.46, *SD* = 23.17). The fewest errors were made for finding the Excel sheet to enter information (*M* = 8.15, *SD* = 15.22). The percentage of errors for finding the Excel sheet was substantially lower than the rest of the navigation tasks, and was probably not representative of navigation. This task was not included in further analyses.

Almost all the presses made during data entry were correct. Of the total presses, 6.5% were errors. The percentage of data entry errors across tasks ranged from 2.67% to 8.83%. The greatest percentage of errors were made when re-naming a folder (*M* = 8.83, *SD* = 9.76), followed by entering appointment information (M = 7.84, SD = 6.19), entering contact information (*M* = 7.52, *SD* = 4.22), typing an email message (*M* = 7.37,

*SD* = 6.68), and entering sentences into Word (*M* = 5.07, *SD* = 4.11). The least percentage of errors was made when entering data in the Excel sheet.

The percentage of errors of each PDA task type across tone discrimination difficulty, as well as the standard errors, is displayed in Figure 3. Participants made a slightly greater percentage of navigation errors in the easy tone discrimination condition compared to hard tone discrimination condition. Similar to navigation tasks, participants made a slightly greater percentage of data entry errors in the easy tone discrimination compared to the hard tone discrimination condition.

Figure 3

A two-way ANOVA was conducted on the error data with the PDA task types (data entry, navigation) and tone discrimination difficulty (easy, hard) as within-subjects factors. The analysis confirmed the observation that participants made more errors while performing navigation tasks than data entry tasks, $F$ (1, 23) = 188.71, $MSE$ = 78.54, $p < .001$, $f$[1] = 2.19. No other effects were significant.

Typing rate was slightly slower in the hard tone discrimination condition (*M* = 12.57, *SD* = 2.26) compared to the easy tone discrimination condition (*M* = 14.59, *SD* = 2.91). Typing rate was the quickest for renaming a folder (*M* = 17.50, *SD* = 4.39), followed by entering sentences in Word (*M* = 15.59, *SD* = 3.86), typing an email message (*M* = 15.12, *SD* = 4.77), entering appointment information (M = 13.65, SD = 3.63), entering contact information (*M* = 10.68, *SD* = 2.02), and entering information in an Excel sheet (*M* = 9.48, *SD* = 1.85). The results using a paired samples *t*-test

[1] Cohen's *f* (1988) is the appropriate effect size measurement used in the context of an *F*-test. Cohen's *f* and eta-squared (a power parameter commonly reported with the *F*-test statistics) are related in the following manner: $f^2 = \text{eta}^2 / (1\text{-eta}^2)$.

revealed that participants entered data at a significantly quicker rate while performing an easy compared to hard tone discrimination task, $t$ (23) = 4.91, $p < .001$, $d$[2] = 0.78.

Average completion time for navigation tasks while completing an easy tone discrimination task was slightly greater ($M$ = 31.85, $SD$ = 9.30) compared to while completing a hard tone discrimination task ($M$ = 24.45, $SD$ = 7.21). The completion times ranged from an average of 55.46 s ($SD$ = 31.48) to 11.86 s ($SD$ = 12.18). Participants took the longest while finding the appropriate screen to rename a folder, followed by finding a voice recording ($M$ = 52.67, $SD$ = 29.11), finding the battery ($M$ = 40.83, $SD$ = 20.86), finding the appointment dates ($M$ = 36.29, $SD$ = 27.08), finding the appropriate date for entering appointment information ($M$ = 31.25, $SD$ = 20.02), finding a picture ($M$ = 30.71, $SD$ = 28.57), composing a new email message ($M$ = 28.13, $SD$ = 24.16), finding the screen that displays the owner of the device ($M$ = 17.58, $SD$ = 14.62), creating a new Word document ($M$ = 15.59, $SD$ = 16.02), creating a new contact ($M$ = 15.59, $SD$ = 16.09), and finding an email message. The results using a paired samples $t$-test confirmed that participants found the required information significantly faster while performing a hard compared to an easy tone discrimination task, $t$ (23) = 3.24, $p < .01$, $d$ = 1.40.

**Tone Discrimination Task**

The dependent measures for the tone discrimination task, in each condition, were the percentage of correct, incorrect, and adjusted identifications of target tones, and the time required to make correct identifications.

shows the mean percentage of correct, incorrect, and adjusted identifications of target tones for each condition. As expected, participants were less accurate while performing a hard compared to easy tone discrimination task in the Bbseline condition.

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[2] Cohen's $d$ (1988) is the appropriate effect size measure to use in the context of a $t$-test on means.

Among the data entry conditions, participants made a greater percentage of correct identifications while completing an easy compared to hard tone discrimination task. Similarly, in the navigation conditions participants made a greater percentage of correct identifications while completing an easy compared to a hard tone discrimination task.

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Overall, the percentage of incorrect identifications was the greatest in the Baseline conditions (*M* = 2.43), followed by the navigation (*M* = 1.82), and data entry conditions (*M* = 1.35). In the baseline condition, participants made approximately twice the percentage of incorrect identifications for the easy tone discrimination task compared to the hard tone discrimination task [see ]. In the navigation conditions, participants made approximately the same percentage of incorrect identifications for an easy and for a hard tone discrimination task. While participants were completing data entry tasks, they made a slightly greater percentage of incorrect identifications while performing a hard versus an easy Tone Discrimination Task.

In order to take into account the different percentage of incorrect identifications across conditions, the adjusted identifications were explored in detail []. The pattern of results for adjusted identifications was the same as for the pattern of correct identifications. A greater percentage of adjusted identifications was found when participants completed an easy version of the Tone Discrimination Task than the hard version. When performed concurrently with data entry tasks, participants made a similar percentage of adjusted identifications in the easy and hard version of the tone discrimination task. The percentage of adjusted identifications was lower while participants performed a hard Tone Discrimination Task compared to an easier version.

A two-way ANOVA conducted on the adjusted identifications data with the task condition (baseline, data entry, navigation) and tone discrimination difficulty (easy, hard)

as the within-subjects factors confirmed the observations. Participants made a significantly greater percentage of adjusted identifications while performing an easy tone discrimination task, $F$ (1, 23) = 33.49, $MSE$ = 394.70, $p < .001$, $f$ = 1.16. A main effect of Ttsk condition was also found, $F$ (2, 46) = 56.99, $MSE$ = 309.87, $p < .001$, $f$ = 2.16. A post-hoc test conducted with Fisher's LSD revealed that the percentage of adjusted identifications in the baseline condition was significantly greater than the data entry condition, and that the percentage of correct identifications in the navigation condition was significantly less compared to the data entry condition.

The critical analyses were to examine whether the percentage of adjusted identifications varied between PDA task types across tone discrimination difficulty. The mean difference of adjusted identifications among navigation conditions ($M$ = 17.14, $SD$ = 22.74) was greater than among data entry conditions ($M$ = 9.51, $SD$ = 21.65). A paired samples $t$-test conducted on the mean differences between the two conditions revealed that the difference approached significance, $t$ (23) = 1.75, $p$ = .09.

Since the pattern of results did not change even when taking into account the incorrect identifications data, only the response times for correct identifications were explored. The summarized results for response times (mean of medians) of correct identifications are displayed in Figure 4. Overall, participants took longer to respond to target tones while performing data entry tasks ($M$ = 861.04) and navigation tasks ($M$ = 947.00) compared to the Baseline condition ($M$ = 787.85). Time required for responding to target tones while completing data entry tasks was approximately the same when participants were concurrently performing an easy or a hard Tone Discrimination Task. However, response time while performing navigation tasks was greater while attending to a hard compared to easy Tone Discrimination Task.

Figure 4

A 2 x 3 ANOVA was conducted on the response time data with the task condition (baseline, data entry, navigation) and tone discrimination difficulty (easy, hard) as the within-subjects factors. The analysis confirmed that participants took significantly longer to correctly identify target tones when performing a hard compared to an easy tone discrimination task, $F(1, 23) = 6.66$, $MSE = 29073.56$, $p < .001$, $f = 0.49$. A significant main effect of task condition was found $F(2, 46) = 19.21$, $MSE = 15852.62$, $p < .001$, $f = 1.23$. The interaction effect was not significant. Post-hoc tests using Fisher's *LSD* revealed that response time was significantly greater while participants were concurrently completing a PDA task. In addition, response time was greater while performing navigation tasks compared to data entry tasks. The interaction was not significant.

**Discussion**

The primary objective of Experiment 2 was to explore whether the findings obtained in Experiment 1 reflected measuring attention or task switching. The second objective was to investigate whether the developed dual-task methodology could be reliably used. We required participants to perform an easy or hard version of the tone discrimination task while completing a set of PDA tasks that either focused on navigation or data entry.

Overall, the navigation task error rate was greater than the data entry error rate. The error rates for both PDA tasks were slightly better when combined with a hard version of a Tone Discrimination Task compared to an easy version, but the difference was not significant. Performing hard tone discrimination slowed down information search; performing easy tone discrimination slowed down data entry speed.

The completion time and data entry speed should be interpreted with caution. The time data reported also reflects the exchange of instructions between the participants and experimenter, and when participants asked for help. One possible interpretation of the finding is that participants asked for more help in one condition, thus slowing down data entry. Another possible interpretation for the findings is that participants was more relaxed when they realized that entering data and attending to easy tone discrimination was not difficult, and therefore took more time to enter the data. In general, PDA task performance was comparable to findings in studies that had participants complete these tasks with full attention (Graf & Li, 2007), indicating that participants were paying attention to performing these tasks.

The percentage of adjusted identifications was significantly lower and the median response time was significantly slower while performing the hard tone discrimination task compared to the easy version in the baseline condition. The findings suggest that the difficulty manipulation was successful, and that the hard version of the task required more attention than the easy version.

As expected, the difference in adjusted identifications was greater between navigation conditions compared to the data entry conditions. Response time was the greatest when participants were completing navigation tasks with a hard tone discrimination task.

We were able to replicate the majority of findings from Experiment 1. Consistent with Experiment 1, participants made more errors in navigation tasks compared to data entry tasks. Overall, the percentage of navigation errors was slightly lower and overall time to complete navigation tasks was slightly quicker compared to Experiment 1. The overall data entry error rate was similar to Experiment 1. However, data entry speed was slightly slower than what was found in Experiment 1.

Overall, the pattern of adjusted identifications was similar to what was found in Experiment 1. The percentage of adjusted identifications was lower when performing a PDA task and a tone discrimination task compared to performing only the tone discrimination task alone. The effect size of adjusted identifications for data entry and navigation conditions were comparable to the results from Experiment 1. Response time for correct identifications while completing data entry tasks was quicker than what was found in Experiment 1. The reduced response time compared to Experiment 1 is most likely due to the reduced inter-stimulus interval. There is evidence that response time varies as a function of inter-stimulus interval (France et al., 2002). Auditory trace decays as a function of time. In longer ISI's, participants take longer to retrieve the comparison tone prior to making a decision.

In summary, the findings from Experiment 2 provide support that a dual-task methodology using tone discrimination is a valid set-up for assessing the attentional demands of PDA tasks. In addition, the replicated findings from Experiment 2 also suggest that this method can be used reliably in the context of measuring attention required by PDA tasks. Finally, Experiments 1 and 2 provide converging evidence that navigation tasks require more attention to perform than text entry tasks.

While there have been many researchers that study attention as a single resource, a second account of attention argues that attention consists of distinct reserves where each resource is responsible for processing different types of information (Baddeley, 1986). The following two experiments were designed to explore whether different types of attention are required to perform navigation and data entry tasks.

## Experiment 3

The purpose of this study was to validate a methodology for exploring the different types of attentional resources required for navigation and data entry tasks. I chose an existing method, described by Brooks (1968), for revealing different types of attention: Visuo-spatial and articulatory/auditory. This method required participants to perform two tasks concurrently. Participants completed a combination of one input task (letter tracing task, sentence decision task) and one output task (pointing, tapping, saying). One input task required visuo-spatial resources (letter tracing task), while the other task required articulatory/auditory resources (sentence decision task). The letter tracing task involved presenting an image of an English block letter (e.g., see Figure 5) and making categorization judgements. For this task, participants were asked to decide whether each corner was the topmost/bottom-most corner in the letter, or whether each corner was on the outside edge of the letter. The sentence decision task required participants to categorize each word in a sentence presented over the speakers. They were required to decide whether each word was a noun/non-noun or article/non-article. For both tasks, participants were required to provide 'yes' or 'no' answers.

Figure 5

The three output tasks required participants to indicate their answers from the Input Tasks in one of three ways. Participants made their responses by a method that required either visuo-spatial resources (pointing), articulatory/auditory resources (saying), or motor abilities (tapping). A combination of these tasks (i.e., one input task and one output task) would be then used in conjunction with the PDA tasks to explore the type of attention required by the PDA tasks.

I expect to find the same pattern of results reported in the original study (Brooks, 1968). Completion times would be greater when both tasks draw on the same type of resources compared to when the two tasks require different attentional resources. Specifically, completion time would be greater for the letter tracing task when responding in a manner that requires visuo-spatial attention compared to responding by a method that requires articulatory/auditory attention (i.e., saying the responses). In addition, I predicted that completion time would be greater for the sentence decision task when verbally indicating the responses compared to indicating answers by a method that requires visuo-spatial processing.

## Methods

### Participants

Twenty-seven undergraduate students were recruited through the subject pool in the psychology department at the University of British Columbia. They were compensated with one course credit in return for their participation. The experiment was conducted with the approval of the University of British Columbia behavioral ethics review board.

### Materials

The stimuli for the letter tracing task consisted of an outline of six block letters. Two letters were for practice trials and the remaining four letters were for the test trials. Each letter for the practice trials [shown in Figure 5] had 12 corners: E, H. Each letter for the test trials [shown in Figure 6] had ten corners: F, N, G, and Z. Each letter was drawn using MS Paint and stored as a bitmap file.

Figure 6

The stimuli for the sentence decision task consisted of six famous English aphorisms (e.g., a bird in the hand is not in the bush). Two sentences were used for the

practice trials, and the remaining four sentences were used for the test trials. Each sentence in the practice trial had a length of twelve words: You'll never plow a field by turning it over in your mind; the grass is always greener on the other side of the fence. Each sentence in the test trial had a length of ten words: Rivers from the hills bring fresh water to the cities; a bird in the hand is not in the bush; there is the low fiend who stole the child's candy; no man who has a wife is still a bachelor. Each sentence was recorded by speaking through a microphone, and stored as a .wav file, with single channel 16-bit PCM coding at a sampling rate of 44.1 kHz.

**Input Tasks**

**Letter Tracing Task**. Stimulus presentation and response recording for the letter tracing task were controlled by a PC, using the EPrime v.1.0 software (Psychology Software Tools Inc., Pittsburg, PA). The stimuli, described in the Materials section, were presented on a 15" monitor.

The letter tracing task required participants to categorize each corner of a block letter. The letter tracing task consisted of two practice trials and four test trials (one trial for each letter). In each trial of this task, a letter was presented on the monitor on a white background. Participants were allowed to view the letter as long as they needed. After participants indicated that they could remember the shape of the letter, the stimulus was taken off the monitor. Participants were instructed to imagine the letter to ensure that they could generate a mental image of the letter. Participants were shown the letter again if they indicated that they could not remember. When participants indicated that they could remember the shape of the letter, the image was taken off the monitor. Next, one of the categorization instructions was presented on the screen. Participants were required to begin the task starting at the bottom left corner of the letter and to categorize the corners in a clockwise direction until all corners were categorized.

In the top/bottom instruction, participants were asked to categorize the corners that were the highest point or the lowest point in the letter as 'yes' and all other corners as 'no' (see Figure 7). For example, the correct sequence of responses for the 'F' stimulus would be "yes, yes, yes, no, no, no, no, no, no, yes". The outside instruction required participant to categorize each corner that touched an imaginary box surrounding the letter as 'yes' and all other corners as 'no' (see Figure 8). The correct sequence of responses for the 'F" stimulus would be "yes, yes, yes, yes, no, no, no, no, no, yes".

Figure 7

Figure 8

**Sentence Decision Task.** Stimulus presentation and response recording for the sentence decision task were controlled by a PC, using the EPrime v.1.0 software (Psychology Software Tools Inc., Pittsburg, PA). The sentences were presented over two speakers.

The sentence decision task consisted of two practice trials and four trials (one trial for each sentence). The sentence decision task required participants to categorize each word immediately after a presented sentence. In each trial of this task, a sentence was presented auditorily through two speakers. After the sentence was presented, participants were asked to repeat the sentence to ensure that they were able to recite the sentence perfectly. The sentence was repeated if participants recited the sentence incorrectly. After correcting the participants, they were asked to repeat the complete sentence again. When participants were able to rehearse the sentence perfectly, one of the two categorization instructions was presented. In the noun instruction, participants were required to categorize each word (in serial order) that was a noun as 'yes' and all

other words as 'no'. In the article instruction, participants were required to categorize each word that was an article as 'yes' and all other words as 'no'.

**Output Tasks**

**Pointing.** A list of Y and N was displayed in a staggered manner on a computer monitor [see Figure 9]. The Y's and N's were staggered to force close visual monitoring of pointing. Each line displayed one Y and one N. A total of 12 lines of Y's and N's were presented on the screen for a practice trial, since there were 12 corners on each stimulus of the practice trial. Ten lines were presented for a test trial, since there were ten corners on each stimulus of the test trial. Participants clicked on either a Y or N on each line to make one response, starting from the top line. Participants used a mouse to point and click at the Y (for yes) and N (for no).

Figure 9

**Tapping.** In the tapping output condition, participants pressed a button on a keyboard that corresponded to a 'yes' with their left index finger and another button for a 'no' response with their right index finger.

**Saying.** In the saying output condition, participants responded by saying 'yes' and 'no' into a microphone.

**Neuropsychological Tests**

A neuropsychological test battery was employed to assess participants' cognitive abilities. The battery consisted of four standardized tests: the Forward Corsi Block tapping task (Corsi, 1972; Kessels, Zandvoort, Postma, Kappelle and Haan, 2000), the Reverse Corsi Block tapping task (Corsi, 1972; Kessels, Zandvoort, Postma, Kappelle & Haan, 2000), the Forwards Digit span test (Wechsler, 1981), and the Reverse Digit Span Test (Wechsler, 1981). The tests were administered according to the standardized

instructions published in each manual. The results of these measures are not pertinent to the objectives of the present thesis and thus will not be included.

**Design**

The design of this experiment consisted of a 2 x 3 factorial design that had input task (letter tracing task, sentence decision task) and output task (pointing, tapping, saying) as within subject factors.

**Procedures**

I tested participants individually in a session that lasted 60 minutes. Upon obtaining their written consent, each participant completed the tasks described below.

There were a total of six conditions in this experiment. In each condition, participants completed either a letter tracing task or sentence decision task, combined with one method of responding: pointing, tapping, saying. Presentation of the six conditions was counterbalanced across participants by means of a Latin Square design.

In each condition, participants were given two practice trials to familiarize them with the task, the categorization instructions, and the method of response. Prior to beginning the practice trials, I explained to participants the goal of the task. For conditions that involved the sentence decision task, I explained to participants that they were to listen to a series of short sentence and make categorization judgments for each word. I then explained each categorization instruction (i.e., noun, article). Once participants indicated that they understood the task, I proceeded to describe the method of response for that condition. After the practice trials were completed, a block of four sentences was run as the test trials. The stimuli and categorization instructions were randomly presented across trials.

For the letter tracing task, I explained to participants that they were required to look at a block letter presented on the monitor and to categorize each corner, in a

clockwise direction, starting from the bottom left corner. For each letter, I told participants they would be asked to make categorization judgments for each corner. Next, I explained each categorization instruction. Once participants indicated that they understood the task, I proceeded to describe the method of response for that condition. These instructions were the same as for the sentence decision task. After the practice trials were completed, a block of four letters were run as the test trials.

I instructed participants to make their responses immediately when they made a categorization. This instruction was given to prevent participants from first collecting several answers and then indicating the responses, which would not reflect completion time produced by the interference. In addition, I told participants to be as accurate as possible in making their responses. The timing for each trial began after the categorization instruction was presented and ended when participants made the last response.

Following the completion of the last condition, I administered the battery of neuropsychological tests. After the last neuropsychological test was completed, participants were given a verbal debriefing, as well as a written debriefing form, and a course credit.

## Results

### Data Preparation

The results from the tasks were screened for outliers, defined as falling more than three standard deviations away from the sample mean. One outlier that was three standard deviations above the mean was found. This outlier was replaced with a non-outlying number, a number that was 3 standard deviations above the sample mean.

One participant did not complete the four test trials of the sentence decision task while making verbal responses. The data from this participant were excluded from the analysis. Data from the remaining 26 participants were used for the analyses.

The dependent measure for the letter tracing task and sentence decision task was the time it took to complete one trial. For each participant, I computed the mean completion time for each condition.

**Input and Output Tasks**

Mean completion time is shown in Figure 10. Overall, completion time for the letter tracing task was 17.73 s (*SD* = .85) and 16.04 s (*SD* = .74) for the sentence decision task, suggesting that the tasks were of approximately the same difficulty. The figure revealed that the two conditions that required overlapping resources had greater completion times compared to other conditions that had an input and output tasks that required different types of resources. When participants responded by pointing to answers, completion time for the letter tracing task (*M* = 26.87, *SD* = 7.34) was approximately twice as long compared to categorizing words in a sentence (*M* = 15.27, *SD* = 4.45). Similarly, completion time was greater when participants made vocal responses for the sentence decision task (*M* = 21.83, *SD* = 6.01) compared to when the performing the letter tracing task (*M* = 13.66, *SD* = 3.57). Completion time in the tapping output condition was approximately the same when performing the letter tracing task (*M* = 12.85, *SD* = 3.57) as in the sentence decision task (*M* = 11.64, *SD* = 3.54).

Figure 10

A two-way ANOVA was conducted on the completion time[s] with the input task (letter tracing task, sentence decision task) and output task (pointing, tapping, saying) as the within-subjects factors. A main effect of output task was found, $F$ (2, 50) = 79.24, *MSE* = 13.05, $p < .001$, $f$ = 0.86. The interaction between input and output task was

also significant, $F$ (2, 50) = 115.38, $MSE$ = 11.03, $p < .001$, $f$ = 2.97. Completion times between the input tasks were not significantly different, $p > .05$.

Two follow-up paired samples $t$-tests were conducted on the completion times to explore whether completion time varied across input and output tasks. Comparison between completion times confirmed the observations. When participants pointed to the answers, they took significantly longer to categorize corners of a letter than to categorize words in a sentence, $t$ (26) = 9.04, $p < .001$. When participants indicated their answers verbally, they took longer to complete the sentence decision task compared to the letter tracing task, $t$ (26) = -6.78, $p < .001$.

**Discussion**

The main purpose of the experiment was to investigate whether the method described by Brooks (1968) provided a reliable and valid means for revealing the different types of attention. Participants were required to perform two tasks concurrently. They were engaged in a task that required primarily visuo-spatial (categorizing corners of a block letter) or verbal resources (categorizing words in a sentence), and they indicated their answers in a manner that required verbally, motor or visuo-spatial resources.

The general pattern of results found in this experiment was consistent with my hypotheses. Completion time was the greatest when participants handled two tasks that required the same resources. The results showed that responding in a verbal manner was slowest while categorizing words in a sentence, and pointing to the answers on a monitor was slowest for categorizing corners of a letter. Completion time for tapping the answers on a keyboard was approximately the same while combined with either input task, suggesting that tapping answers required neither visuo-spatial nor verbal resources.

However, there are several differences between the results obtained from this experiment and the results reported by Brooks (1968). In this experiment, participants took 15 s to complete the sentence decision task when pointing to the answers, while the completion time was slightly shorter (10 s) in the original study. The greater completion time found in this experiment can be explained by the different technique used record to the responses. While Brooks (1968) required participants to circle the answers on a piece of paper, I required participants to use a mouse and select their answers on a computer. Participants may have been less familiar with the mouse and computer method than the typical pencil and paper method, and this may explain why the completion time was greater in the present experiment.

In the original study, participants took almost twice as long to tap the answers for the letter tracing task ($M$ = 14.1 s, $SD$ = 5.4) compared to the sentence decision task ($M$ = 7.8 s, $SD$ = 2.1) while I found that completion time was approximately the same for both letter tracing ($M$ = 12.85, $SD$ = 3.57) and sentence decision task ($M$ = 11.64, $SD$ = 3.54). The effect size for the mean difference in completion times for Brook's study is $d$ = 1.54) and $d$ = 0.34 for the mean difference in completion times for Experiment 3. Once again, the difference in mean completion times found in Brook's study and my experiment may be explained by the method used to record the responses. In the original study, Brooks recorded the answers by having participants touch either the Y or N printed on a piece of paper for their responses. Participants were likely reading the Y or N prior to touching the answer. Thus, the response record method was likely to require some visuo-spatial resources, which resulted in greater completion time for performing the letter tracing task.

Finally, a much larger difference in completion time was found in this experiment between the letter tracing and sentence decision tasks when participants responded by

saying the answers compared to what was reported by Brooks (1968). Specifically, in this experiment, an eight second difference was found between the two input tasks ($d$ = 1.66), while the original study found only a two second difference between the same tasks ($d$ = .77). The difference in completion times and effect sizes may be explained by the increased number of participants in the study, which may reflect a more accurate understanding of the specific type of processing required for these tasks.

## Experiment 4

The objective of this experiment was to explore the type of attention required of two PDA task types: Navigation and data entry. The dual task methodology was used to approach this objective. The input tasks validated in Experiment 3 (letter tracing task and sentence decision task) were used as the secondary tasks. Participants were required to perform either a letter tracing task or a sentence decision task concurrently with either a navigation or data entry task on the PDA.

### Method

#### Participants

Thirty undergraduate students were recruited through the subject pool in the psychology department at the University of British Columbia. They were compensated with one course credit in return for their participation. The experiment was conducted with the approval of the University of British Columbia behavioral ethics review board.

#### Apparatus

The same apparatus was used as in Experiment 1.

#### Input Tasks

The letter tracing task and sentence decision task were used as the secondary tasks. The stimuli for the tasks, as well as the setup for the tasks are described in the Methods section of Experiment 3.

#### Output Tasks

Participants responded in one of two methods: verbally saying the answers or tapping the answers. These methods of response are described in the Methods section of Experiment 3.

## PDA Tasks

Sixteen PDA tasks were selected, two per condition (a factorial combination of input task, output task and PDA task type yielded eight conditions). Eight tasks required searching through the menu layers to find information (find font size, retrieve appointments, check the battery, find voice message, create new folder, find Bluetooth version, find themes, and load webpage), and eight tasks required entering data.

Two of the navigation tasks were identical to the ones used in Experiment 1 (check the battery, retrieve appointments) and one of the navigation task was the same one used in Experiment 2 (find voice message). Below includes a brief description of each navigation task.

**Find font size.** The instructions for this task directed participants to find the font size that displays the text on the PDA.

**Create new folder** For this task, participants were required to find the program that had the option to create a new folder.

**Find Bluetooth version.** This task required participants to find the Bluetooth application and to display the current version of the application.

**Find themes.** Participants were instructed to find the screen that showed the available themes of the device.

**Load a webpage.** For this task, participants were instructed to locate the saved webpage www.hotmail.com under the Favorites category and to load this webpage.

The information for the data entry task consisted of eight famous English aphorisms, each one sentence in length. The sentences ranged from 31 to 35 presses, five to seven syllables and five to seven words. Participants entered one sentence for each data entry task. Each of the PDA tasks can be completed in a number of different

ways. Table 4 shows the number of number of steps required for completing each in the most efficient or optimal manner.

Table 4

**Design**

The design of this experiment consisted of a 2 x 2 x 2 that had input task (letter tracing task, sentence decision task), output task (tapping, saying) and PDA task (navigation, data entry) as the within subjects factors.

**Procedures**

I tested participants individually in a session that lasted 60 minutes. Upon obtaining their written consent, each participant completed the tasks described below.

Each participant completed eight conditions in this experiment. Each condition consisted of a set PDA tasks listed in Table 4 combined with an input task and an output task. The eight conditions were presented in a counterbalanced order by means of a complete Latin Square design.

Prior to beginning each condition, participants were given two practice trials to familiarize them with the input task. Specifically, participants were given detailed instructions for how to complete the secondary task and the procedures for the method of response. These instructions were the same as Experiment 3 and are described in the Procedures section of Experiment 3. The sequence of events for each trial is also described in the Procedures section in Experiment 3.

Participants then completed the PDA tasks listed in Table 4 together with an input task (i.e., letter tracing task, sentence decision task) and method of response for the secondary task (i.e., tapping, saying). I instructed participants to focus on completing the PDA tasks accurately and quickly, but to make responses for the input task whenever possible.

Before participants started each PDA task, I gave a verbal explanation of the goal of each task. For navigation tasks, I showed participants a written description of the task and explained the goal of the task. I removed the written material from view once participants indicated that they understood the task. For data entry tasks, participants were first provided with the sentence of the to-be-entered information. Next, I asked participants to recite the sentence to ensure that they were able to rehearse the material from memory. I corrected any incorrect words recited by the participant. After correcting the participants, I asked them to repeat the complete sentence again. When participants were able to recite the sentence perfectly, I removed the materials with the written sentence.

The procedures for starting and ending the letter tracing and sentence decision task were the same as in Experiment 3 and are described in the Procedures section of Experiment 3.

The procedures for recording participant interactions with the PDA were the same as in Experiment 1 and are described in the Procedures section of Experiment 1.

Following the completion of the last condition, participants were given a verbal debriefing, as well as a written debriefing form, and a course credit.

## Results

### Data Preparation

The coding manual for the PDA tasks was developed in the same way as in Experiment 1. The method for coding PDA task performance was same as in Experiment 1. Performance for the concurrent tasks was calculated in the same way as in Experiment 3.

I examined the data from the input tasks and corrected for coding errors until accuracy was greater than 99%. The results from the input tasks and PDA tasks were

screened for univariate outliers, defined as a score falling more than three standard deviations away from the sample mean. No outliers were found from the input tasks. Three outliers were found from the PDA task data. Each outlier was replaced with a non-outlying value, a number either 3 standard deviations above or below the sample mean, respectively.

Twelve participants did not complete at least a single trial on the concurrent tasks while they were performing either the data entry or navigation tasks. The data from these participants were excluded from the analysis. Data from the remaining 18 participants were used for the analyses.

**PDA Tasks**

The dependent measures for the PDA tasks were the percentage of correct presses, and the percentage of errors for data entry and navigation tasks, speed of data entry, and the amount of time to complete navigation tasks.

Overall, two-thirds of the presses in navigation tasks were correct ($M$ = 62.04). The percentage of PDA tasks errors as a function of input task, output task, and PDA task type are shown in Figure 11. Overall, error rates for navigation tasks were similar when combined with either the letter tracing task ($M$ = 40.41) or sentence decision task ($M$ = 44.33). However, error rates for navigation tasks varied across the input task and the output task. When concurrently performing the letter tracing or sentence decision task, error rates for navigation tasks were greater while making motor responses ($M$ = 47.63) compared to vocal responses ($M$ = 37.11). However, this difference was greater when combined with the letter tracing task as compared to the sentence decision task. Participants made a greater percentage of errors while concurrently performing the letter tracing task when making motor responses ($M$ = 47.36, $SD$ = 20.34) compared to when making vocal responses ($M$ = 33.45, $SD$ = 19.72). When combined with the

sentence decision task, errors from the navigation tasks were only slightly when making motor responses (*M* = 47.90, *SD* = 15.88) compared to making vocal responses (*M* = 40.77, *SD* = 16.44).

Figure 11

An in-depth examination of the error rates for navigation tasks revealed that the percentage of errors ranged from 28.23% (*SD* = 28.42) to 57.16% (*SD* = 26.00). Participants made the most errors when finding the themes in the PDA, followed by finding the font size (*M* = 55.42, *SD* = 22.18), creating a new folder (*M* = 47.95, *SD* = 20.21), finding the Bluetooth version (*M* = 47.84, *SD* = 22.30), finding the appointment date (*M* = 39.31, *SD* = 26.22), finding the voice message (*M* = 37.11, *SD* = 24.47), finding the battery (*M* = 30.30, *SD* = 25.88), and loading a webpage.

The majority of presses while entering data were correct (*M* = 87.00). Overall, the percentage of data entry errors were similar when concurrently performing a letter tracing task (*M* = 11.96) or sentence decision task (*M* = 14.44). Participants made a slightly greater percentage of errors in data entry tasks while concurrently performing the letter tracing task and making vocal responses (*M* = 12.24, *SD* = 4.84) compared to when making motor responses (*M* = 11.69, *SD* = 6.72). Similarly, participants made a slightly greater percentage of errors for the sentence decision task when making vocal responses (*M* = 15.42, *SD* = 8.29) compared to when making motor responses (*M* = 13.47, *SD* = 7.39).

Error rates for the data entry tasks ranged from 10.45% (*SD* = 8.69) to 17.04% (*SD* = 11.58). Participants made the most errors while entering 'chances favors the prepared mind', followed by entering 'don't bite the hand that feeds you' (*M* = 15.92, *SD* = 18.22), 'all things come to him who waits' (*M* = 14.27, *SD* = 9.38), 'birds of a feather

flock together' ($M$ = 13.16, $SD$ = 8.60), 'a rolling stone gathers no moss' ($M$ = 12.93, $SD$ = 7.58), 'look on the sunny side of life' ($M$ = 12.67, $SD$ = 7.46), 'every cloud has a silver lining' ($M$ = 11.36, $SD$ = 6.42), and 'good fences make good neighbors'.

An ANOVA conducted on the error steps data with the input task, output tasks and PDA task as the within-subject factors revealed a significant main effect of PDA task, $F$ (1, 17) = 107.90, $MSE$ = 283.85, $p < .05$, $f$ = 2.44, such that participants made a significantly greater percentage of errors in navigation tasks compared to data entry tasks. A two-way interaction was found between output task and PDA task, $F$ (1, 17) = 5.66, $MSE$ = 220.23, $p < .05$, $f$ = 0.51. Follow-up tests using a Bonferroni correction were conducted to explore the differences in percentage of errors. For navigation tasks, participants made a significantly greater percentage of errors while indicating their answers for the input task by tapping compared to by saying. No other differences were significant.

Typing speed ranged from 4.28 WPM ($SD$ = 1.49) to 8.20 WPM ($SD$ = 4.19). Typing rate was the quickest for 'Every cloud has a silver lining', followed by 'Birds of a feather flock together' ($M$ = 7.43, $SD$ = 2.66), 'Good fences make good neighbors' ($M$ = 7.21, $SD$ = 2.38), 'A rolling stone gathers no moss' ($M$ = 6.87, $SD$ = 1.99), 'Look on the bright side of things' ($M$ = 6.11, $SD$ = 3.63), 'Don't bite the hand that feeds you' ($M$ = 5.42, $SD$ = 1.80), 'All things come to him who waits' ($M$ = 5.18, $SD$ = 1.53), and 'Chance favors the prepared mind'. The summary of typing rate by the input task and output task is shown in Figure 12. Typing rate was slightly slower while participants were concurrently performing the sentence decision task ($M$ = 5.23) compared to the letter tracing task ($M$ = 7.42).

Figure 12

An ANOVA conducted on the typing speed data from the data entry tasks with the input task and output task as within-subject factors revealed a significant main effect of input task, $F(1, 17) = 23.28$, $MSE = 3.73$, $p < .001$, $f = 1.11$, such that typing speed was slower while concurrently performing a sentence decision task. A significant interaction was also found, $F(1, 17) = 11.46$, $MSE = 5.16$, $p < .05$, $f = 0.48$. Follow-up tests using a Bonferroni correction were conducted to explore the differences in the typing speed across conditions. Overall, typing speed while performing the sentence decision task was significantly slower than concurrently performing the letter tracing task. In addition, typing speed was significantly slower for the sentence decision task when responding vocally compared to tapping the answers.

Completion times ranged from 40.22 s ($SD = 32.45$) to 94.67 s ($SD = 57.70$). Participants took the longest while trying to find the option to change the font size, followed by creating a new folder ($M = 88.56$, $SD = 24.86$), finding the available interface themes ($M = 87.78$, $SD = 52.03$), finding the version of the Bluetooth ($M = 77.39$, $SD = 38.09$), finding a voice recording ($M = 69.94$, $SD = 50.00$), finding the battery status ($M = 61.71$, $SD = 44.02$), finding the appointment date ($M = 58.56$, $SD = 34.32$), and loading a webpage. Overall, completion time for navigation tasks was greater when participants concurrently performed the sentence decision task ($M = 73.49$) compared to the letter tracing task ($M = 66.61$). As shown in Figure 13, completion time was greatest when participants performed the Sentence Decision task by tapping the responses ($M = 82.97$, $SD = 21.17$). Completion times were similar in the three other conditions.

Figure 13

An ANOVA was conducted on the completion time data from navigation tasks with the input task and output task as the within-subject factors. The results revealed no significant effects.

**Secondary Tasks**

Completion time for the letter tracing and sentence decision task as a function of input task, output task, and PDA task type is shown in Figure 14. Overall, participants took slightly longer to complete the sentence decision task ($M$ = 28.20) compared to the letter tracing task ($M$ = 26.03). While performing a navigation task, completion time for the letter tracing task was slightly greater ($M$ = 28.61) compared to the sentence decision ($M$ = 27.64). While performing a data entry task, completion time for the sentence decision task was greater ($M$ = 28.77) compared to the letter tracing task ($M$ = 23.45).

Figure 14

An ANOVA was conducted on the completion time data with the input task, output task and PDA task type as the within-subject factors. The results revealed a significant main effect of output task, $F$ (1, 17) = 4.93, $MSE$ = 98.43, $p < .05$, $f$ = 0.47. A significant two-way interaction was found between input task by output task, $F$ (1, 17) = 11.54, $MSE$ = 60.52, $p < .05$, $f$ = 0.77, and input task by PDA task type, $F$ (1, 17) = 4.52, $MSE$ = 78.82, $p < .05$, $f$ = 0.44. No other main effects or interactions were significant.

Follow-up tests using a Bonferroni correction were conducted to explore the differences in the completion times across conditions. The sentence decision task and tapping was significantly quicker than by tapping. Completion time was significantly greater when participants performed the letter tracing task and navigation tasks.

Completion time was greater when participants combined the sentence decision task with data entry tasks compared to navigation tasks, but the difference was not significant.

**Discussion**

The primary objective of Experiment 4 was to explore the types of attention, required by navigation and data entry tasks. We required participants to perform a second task that either required visuo-spatial (i.e., letter tracing task) or auditory/articulatory (i.e., sentence decision task) resources in combination with a data entry or navigation task.

As was found in Experiment 1 and 2, the overall error rates for navigation tasks were greater than data entry tasks. However, performance for the PDA tasks from this experiment was worse than what was found in Experiment 1 and 2. Participants made a greater percentage of errors for both navigation and data entry tasks, entered data at a slower rate, and took longer to find the target screen for navigation tasks.

Completion time for the input tasks (i.e., letter tracing task, sentence decision task) by output tasks (i.e., saying, tapping) revealed the same patterns as in Experiment 3. Completion time for the letter tracing task did not differ whether participants indicated their answers by tapping or calling out the answers. The completion time for the sentence decision task was greater when participants indicated their responses by saying the answers than by tapping out the answers. These findings are consistent with previous notions that tapping the answers is primarily a motor activity, and thus should not interfere with processing with either input task, while saying the answers requires mainly articulatory/auditory resources.

For navigation or data entry tasks, the error rates did not differ while performing the letter tracing task or the sentence decision task. The differences in PDA task error

rates were revealed by the combination of input and output task. Navigation error rates were significantly higher when participants were asked to indicate their responses by tapping the answers compared to saying the answers, but the difference was quite small. The opposite was found for data entry tasks. For both the letter tracing and sentence decision task, participants made a greater percentage of data entry errors while responding vocally compared to tapping the answers. However, none of the data entry error rates across conditions were significantly different.

Overall, typing speed was slower while performing the sentence decision task compared to the letter tracing task. Moreover, typing speed was slightly slower while performing the sentence decision task and responding vocally compared to responding by tapping. However, none of these differences were statistically different. These findings suggest that the slower typing rate is a result of the demands placed on the auditory/articulatory resource when performing data entry and concurrently making verbal responses.

One of the possible reasons for the elevated error rates, greater completion times and slower typing speeds for the PDA tasks is the greater resource demands for the letter tracing and sentence decision task, compared to a tone discrimination task. This is understandable since the letter tracing and sentence decision task required much more resources at any moment compared to a tone discrimination task. Performing tone discrimination simply requires the participant to attend to and to compare whether the previously presented tone and the present tone sound different. The response is a binary decision, either the tones are the same or they are not the same. Whereas for the input tasks in this experiment, participants were required to first hold in mind the stimuli (e.g., a picture of the letter or the words in the sentence), then retrieve the categorization instructions, and finally make categorization judgements.

Thus the elevated PDA error rates can be partly attributable to the fact that performing the concurrent tasks by itself is fairly difficult.

Completion times for the secondary tasks varied as a function of the output task. The most prominent effect can be seen when participants were performing the sentence decision task. Completion time was greater when participants indicated their responses by saying the answers compared to tapping their answers on a keyboard. This finding is consistent with the notion that categorizing words in a sentence and indicating responses verbally both require auditory/articulatory resources.

The critical results that are pertinent to the objective of this experiment are the completion time for the secondary tasks when combined with the PDA tasks. The results revealed that data entry requires more auditory/articulatory resources, while navigation requires both visuo-spatial and auditory/articulatory resources, but more of the former.

## General Discussion

The overall goal of this thesis was to investigate the attentional demands of various PDA tasks. To achieve this goal, I used several approaches. The first approach was to validate a modified version of the dual-task methodology to assess the amount of attentional demands of the PDA tasks. The second approach was to explore the amount of attention required by the PDA tasks within the dual-task methodology framework. The third approach was to validate two tasks that would reveal the different types of attention. The fourth approach was to explore the types of attention required by these PDA tasks using the dual-task methodology with the tasks validated in the third approach. The main findings of these four approaches were discussed in Experiments 1 through 4, and will be briefly summarized here. The implications for design will be discussed, followed by limitations and directions for future research.

### Summary of Research Findings

The first approach towards achieving the goal of this thesis was to explore the attentional demands of navigation and data entry tasks using a dual-task methodology developed for this purpose. This approach forms the investigation reported in Experiment 1. Using the tone discrimination task as the secondary task, the results revealed that performance for the tone discrimination task was lower when concurrently completed with the navigation tasks compared to data entry tasks.

The results reported in Experiment 1 were followed up in Experiment 2 in order to clarify whether the developed methodology assessed the attentional demands or the difficulty of task switching. A new level of difficulty was added to the tone discrimination task (i.e., easy and hard) that would manipulate the required attention for the tone discrimination task, but not the difficulty of switching between tone discrimination and a PDA task. The pattern of results from the tone discrimination task revealed that the

methodology assessed attention. Based on these findings, it was suggested that navigation requires more attention than data entry.

In an investigation to find out whether navigation and data entry tasks requires different types of attention, which forms the basis of Experiment 3 and 4, I first validated a method described by Brooks (1968) which may be used to reveal the types of attention. The results suggested that the method revealed two tasks that drew on visuo-spatial or auditory/articulatory resources.

Using the dual-task methodology in Experiment 4, I had participants complete a PDA task concurrently with one of the tasks validated in Experiment 3 in order to find out whether different types of attention were required for the PDA tasks. The findings revealed that data entry drew heavily articulatory/auditory resources, whereas navigation required both articulatory/auditory and visuo-spatial resources, but more of the latter.

**General Limitations**

There are several limitations to the experiments reported in my thesis. First, all of the participants were undergraduate students and may not be representative of the population, especially of older adults. There are several reasons why this is a concern. First of all, attentional capacity, in addition with other cognitive abilities, has been proposed to reduce with aging. Second, older adults are less familiar with technology, a factor known to influence the attention required to use technology. Due to both of these reasons, the secondary task decrements are likely to reveal a larger effect with older adults than with undergraduates. As a result, caution must be taken when generalizing the results of this study to an older population.

A second limitation concerns the research design of Experiment 2 and 4. Ideally, the design should also have included complete counter-balancing of the combination of

PDA task sets with the conditions of the secondary task, such that each PDA task appeared equally likely with each combination of the conditions of the secondary task. Thus, the findings are confounded with both the intended manipulations from the experiments, as well as possibly the nature of the specific PDA tasks that were combined with each of the conditions. In order to perform complete counter-balancing with the PDA task sets, I would require a total of 64 participants for Experiment 2, and 512 participants for Experiment 4. However, obtaining a sample of this size was not feasible during the course of the academic year. Follow-up studies in the near future can be conducted to increase the samples to appropriate sizes for further investigation. For the moment, caution should be taken when interpreting these results.

The third limitation involves the input tasks used in Experiment 4. While the tasks were valid for assessing the types of attention required by the PDA tasks, I believe that the input tasks were too difficult to be performed simultaneously with the PDA tasks. The elevated percentage of errors, greater completion times for navigation tasks, and slower typing speed compared to Experiment 1 and 2 indicate that participants were having difficulty performing the PDA tasks well. This finding may suggest that performing a input task and a PDA task were simply too attention demanding, and found it difficult to maintain PDA task performance while trying to perform a input task. To fully assess the type of attention required, another set of concurrent tasks may be needed.

Finally, technology familiarity of the participants was not assessed in these experiments. Familiarity of the task is known to influence the amount of attention required to perform the task. However, while technology familiarity within the undergraduate population is likely to differ among individuals, the variability should be quite small. In addition, at the time that these experiments were conducted the device was new and it was unlikely that participants had any experience in using this specific

device. This reasoning is supported by the small variability seen in the performance measures of the PDA tasks. However, a follow-up study that also assesses the technology familiarity would strengthen the validity of the findings.

**Implications for Design**

As mentioned in the introduction, PDAs are frequently used in various environments. Thus, a number of guidelines and principles can be implemented to ease the attentional demands in order to facilitate efficiency and efficacy. First, to reduce the amount of attention placed on navigation, one of the suggestions would be to reduce the number of menu layers required to find the target screen. Across the experiments, trying to locate the Excel worksheet was one of the tasks performed most efficiently and easily (i.e., least amount of time and errors). One of the possible reasons is that the Excel shortcut shows up on the Start menu after the first access. Thus, after pressing the Start menu, participants could easily recognize the option. For younger adults where technology use is frequent and varied, this design suggestion may be even more effective for older users where technology familiarity is low.

However, reducing the levels in the hierarchy may lead to interfaces with many menu options, creating an environment with too many choices that may overload attention. This is especially true for PDAs, where screen space is limited and there is a trade-off with displaying the amount of information and the visual clarity of which the information can be viewed. Therefore, it is important that the navigation structure is balanced between depth and breadth, so that the items in each menu and number of steps that have to be taken to complete a task are balanced (Westerman, 1995).

There is previous research that demonstrates that the organization of menu structures can influence attentional demands. Westerman, Davies, Glendon, Stammers and Matthews (1995) found that a linear information structure was beneficial for all age

groups, in terms of search times. Stanney & Salvendy (1995) found that 2D visual hierarchies (all levels visible) and linear structures (open folders with their files presented) were more efficient in supporting individuals with low spatial ability than interfaces where some parts of the information structure were hidden (buttons presenting only main categories). Based on these findings, interfaces that are rich in presenting the structure of the information space may remove the need to mentally construct the environment, which in turn could be beneficial for individuals with low spatial ability (Stanney & Salvendy, 1995; Vincente & Williges, 1988).

The second recommendation concerns the visual presentation of information. From informal observations, I noticed that participants spent longer looking at screens that displayed more icons and menu options than when fewer options were available. It is important that the user is able to focus the attention on the task at hand. While engaged in multiple activities simultaneously, irrelevant information or cluttered backgrounds on a computer screen can be distracting (Connelly & Hasher, 1993). Interfaces with reduced information content make it easier to focus attention on relevant information and reduce the time spent on information searchers. Aid in focusing attention can be provided by structuring the information, providing spatial and temporal cues, and manipulating the screen layout (Singh, 2000; see Preece, Rogers, Benyon Holland & Carey, 1994).

Presenting information to various sensory channels can reduce the attentional load on one single system. The capacity of the sensory system limits the amount of information that can be learnt or absorbed. Taking advantage of all the available sensory systems by presenting information via different systems can facilitate acquisition of knowledge. For example, Brünken, Steinbacher, Plass and Leutner (2002) found that audiovisual presentation of text-based and picture-based learning materials

induced less cognitive load, and facilitated knowledge acquisition, compared to the visual-only presentation of the same material. Tardieu and Gyselinck (2003) investigated whether the use of multimodal information presentation would reduce cognitive overload on working memory by using the subsystems in working memory.

Finally, providing environmental support might enhance learning and subsequent search performance. Environmental support consists of information in the environment that facilitates encoding or retrieval of information and can reduce the amount of cognitive processing that is needed (Jones & Bayen, 1998). Navigation is effortful and attention demanding. One suggestion is to provide certain pop-up dialog boxes that may guide finding the task based on the statistical probability of the most commonly used applications. However, it is also important to consider whether or not the environmental support increases the cognitive demands to the point that it becomes too demanding. It is therefore important to investigate which type of support considered to be useful for different tasks, and to what extent individuals can make use of the environmental support that is provided (McDowd & Shaw, 2000).

**Future Directions**

As described in the introduction, one of the primary motivations for conducting this line of research is to understand the factors that affect usability of PDAs. The series of experiments described in this thesis formed as pilot studies to which the methods could be applied to assess the attentional demands of PDA use across the lifespan.

One line of future research can explore how attentional demands of different PDA tasks change across the adult lifespan. The findings from the experiments in this thesis have suggested that navigation is more demanding than data entry. From what is known in the area of cognitive aging, aging is associated with loss of available resources (Craik, 1983; Craik & Byrd, 1982; Rabinowitz, Craik & Ackerman, 1982).

Given these two premises, it would be reasonable to predict that PDA task performance would be worse among older adults compared to younger adults, which could be partly explained by the reduced attentional capacity from aging. Although previous research has led to the formulation of extensive design guidelines for cell phone interfaces, web pages, and various software applications for the PC, there is no research that specifically focuses on reducing attentional load on PDA tasks. Since PDAs relies on a different interaction technique than a desktop or laptop computer (i.e., stylus and touchscreen), and has a different screen size than other technological devices (such as cell phones or personal computers), it is reasonable to believe that the findings will yield something novel.

Another line of this type of research is to investigate whether aging has the same effect on the different types of attentional resources. At present, there is a lot of research that indicates that aging affects spatial ability, but not verbal ability. In addition, there has been no study that compares the two types of attention. One of the implications of this theoretical research is to determine whether to focus innovative research and design guidelines to change PDA tasks that take advantage of the ability that is less susceptible to aging. The other implication would be to complement interface and device specifications with training.

The third line of research can explore whether older versus younger adults are more challenged by navigation than data entry tasks. In general, most studies that have investigated the effects of age on technology use have found that older adults typically make more errors and take longer to complete the task compared to younger adults on both data entry tasks (Brewster & Cryer, 1999; Czaja, Hammond, Blascovich & Swede, 1989; Czaja & Sharit, 1998) and information search tasks. In a pilot study with individuals ranging from 18 to 85 years of age, we found that older adults made more

errors on navigation and data entry tasks, and took longer for navigation tasks compared to younger adults (Graf & Li, 2007). However, it is unclear the specific nature of each task that makes them more difficult to perform by older adults. Future studies can explore the specific factors that may contribute to the difficulty of the task.

## Conclusion

The results from the experiments of my thesis demonstrated that navigation and data entry performed on a PDA differ in the amount of attention, and type of attention. These findings are consistent with the intuition that data entry is easier since it involves mostly a motor activity, whereas navigation requires a greater amount of cognitive processing, such as remembering what you need to find, where you are in the system, and the correct options that will lead to the desired application. The findings are also consistent with the notion that data entry involves primarily rehearsing the to-be-entered information while navigation requires creating a mental model of the menu system. As discussed in the introduction, performing these tasks under highly attention demanding environments may compromise usability of certain tasks. The results from this thesis contribute to the theoretical understanding of the interaction between the attentional demands of PDA tasks and the environment. This understanding opens up the possibilities of further research that could be conducted to pinpoint the specific characteristics of these tasks that make them attention demanding. These findings will have implications for the design guidelines of PDAs and, and perhaps, other technologies.

Table 1

**The number of Optimal Steps/Presses for each PDA Task as an Indicator of Task Difficulty**

| PDA Tasks | Number of required steps | | | Order of Tasks |
|---|---|---|---|---|
| | Navigation | Data entry | Total | |
| Navigation tasks | | | | |
| Check the battery | 4 | / | 4 | 2 |
| Retrieve appointments | 6 | / | 6 | 4 |
| Find a picture | 4 | / | 4 | 5 |
| Data entry tasks | | | | |
| Enter contact information | 3 | 116 | 119 | 1 |
| Enter expense information | 4 | 74 | 78 | 3 |
| Make an appointment | 6 | 23 | 29 | 6 |
| Total steps | 25 | 213 | 238 | |

Table 2

**Percentage of Correct, Incorrect, and Adjusted Identifications in the Tone Discrimination Task across Conditions**

| Identification Test Score | Condition | | | | | |
|---|---|---|---|---|---|---|
| | Baseline | | Data Entry | | Navigation | |
| | *M* | $CI_{.95}$ | *M* | $CI_{.95}$ | *M* | $CI_{.95}$ |
| Correct | 75.00 | 70.21, 79.79 | 48.10 | 39.73, 56.46 | 32.78 | 24.95, 40.61 |
| Incorrect | 9.50 | 5.43, 13.56 | 6.26 | 4.39, 8.12 | 9.31 | 5.85, 12.77 |
| Adjusted | 65.50 | 58.39, 72.61 | 41.84 | 32.78, 50.91 | 23.47 | 14.05, 32.90 |

Table 3

**The Number of Steps/Presses Required by each PDA Task across Tone Discrimination Task Difficulty**

| PDA Tasks | Number of required steps | | | Order within Sets |
|---|---|---|---|---|
| | Navigation | Data entry | Total | |
| Easy Navigation[a] | | | | |
| Find Picture | 4 | / | 4 | 1 |
| Retrieve Appt Information | 6 | / | 6 | 2 |
| Check Battery | 4 | / | 4 | 3 |
| Easy Entry[b] | | | | |
| Enter Sentences | 4 | 88 | 92 | 1 |
| Name New Folder | 5 | 19 | 24 | 2 |
| Enter Contact Information | 3 | 116 | 119 | 3 |
| Hard Entry[c] | | | | |
| Enter Email Message | 4 | 36 | 40 | 1 |
| Enter Appointment Information | 6 | 23 | 29 | 2 |
| Enter Expense Information | 4 | 74 | 78 | 3 |
| Hard Navigation[d] | | | | |
| Find Voice Recording | 5 | / | 5 | 1 |
| Find Email Address | 3 | / | 3 | 2 |
| Find Owner | 3 | / | 3 | 3 |
| Total steps | 48 | 356 | 404 | |

[a] Set A
[b] Set B
[c] Set C
[d] Set D

Table 4

**Percentage of Correct, Incorrect, and Adjusted Identifications in the Tone Discrimination Task across Task Conditions and Tone Discrimination Difficulty**

| Identification Test Score | Condition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline | | | | Data Entry | | | | Navigation | | | |
| | Easy | | Hard | | Easy | | Hard | | Easy | | Hard | |
| | *M* | *SE* | *M* | *SE* | *M* | *SE* | *M* | *SE* | *M* | *SE* | *M* | *SE* |
| Correct | 90.23 | 2.06 | 60.63 | 5.07 | 53.09 | 5.49 | 43.94 | 5.36 | 45.83 | 5.62 | 28.86 | 5.07 |
| Incorrect | 1.82 | 0.34 | 3.04 | .74 | 1.17 | 0.23 | 1.53 | 0.27 | 1.73 | 0.36 | 1.91 | 0.41 |
| Adjusted | 88.42 | 2.13 | 57.59 | 5.62 | 51.92 | 5.51 | 42.40 | 5.42 | 44.10 | 5.62 | 26.96 | 5.14 |


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Table 5

**The number of Steps/Presses Required by each PDA Task Across Conditions**

| | Number of required steps | Order within Sets |
|---|---|---|
| Letter Tracing/Tapping/Navigation | | |
| Find font size | 6 | 1 |
| Retrieve appointments | 5 | 2 |
| Letter Tracing/Saying/Navigation | | |
| Check the battery | 5 | 1 |
| Find voice message | 4 | 2 |
| Sentence Decision/Tapping/Navigation | | |
| Create new folder | 5 | 1 |
| Find Bluetooth version | 5 | 2 |
| Sentence Decision/Saying/Navigation | | |
| Find themes available in device | 3 | 1 |
| Load webpage | 4 | 2 |
| Letter Tracing/Tapping/Data entry | | |
| A rolling stone gathers no moss. | 32 | 1 |
| Good fences make good neighbors. | 32 | 2 |
| Letter Tracing/Saying/Data Entry | | |
| Birds of a feather flock together. | 34 | 1 |
| Every cloud has a silver lining. | 32 | 2 |
| Sentence Decision/Tapping/Data Entry | | |
| Look on the sunny side of life. | 31 | 1 |
| All things come to him who waits. | 33 | 2 |
| Sentence Decision/Saying/Data Entry | | |
| Chance favors the prepared mind. | 32 | 1 |
| Don't bite the hand that feeds you. | 35 | 2 |

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Figure 1. Picture of the device used for the experiment.

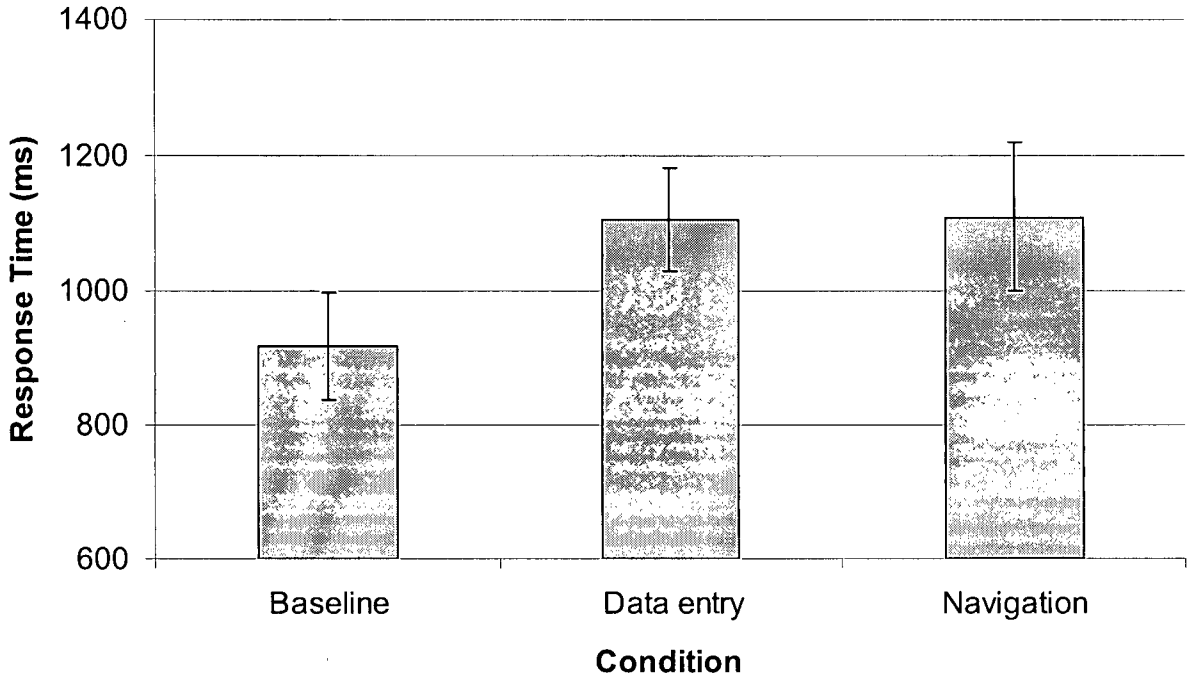


Figure 2. Response time (mean of median) for correct identification of target tones across conditions.

† vertical bars represents 95% confidence intervals

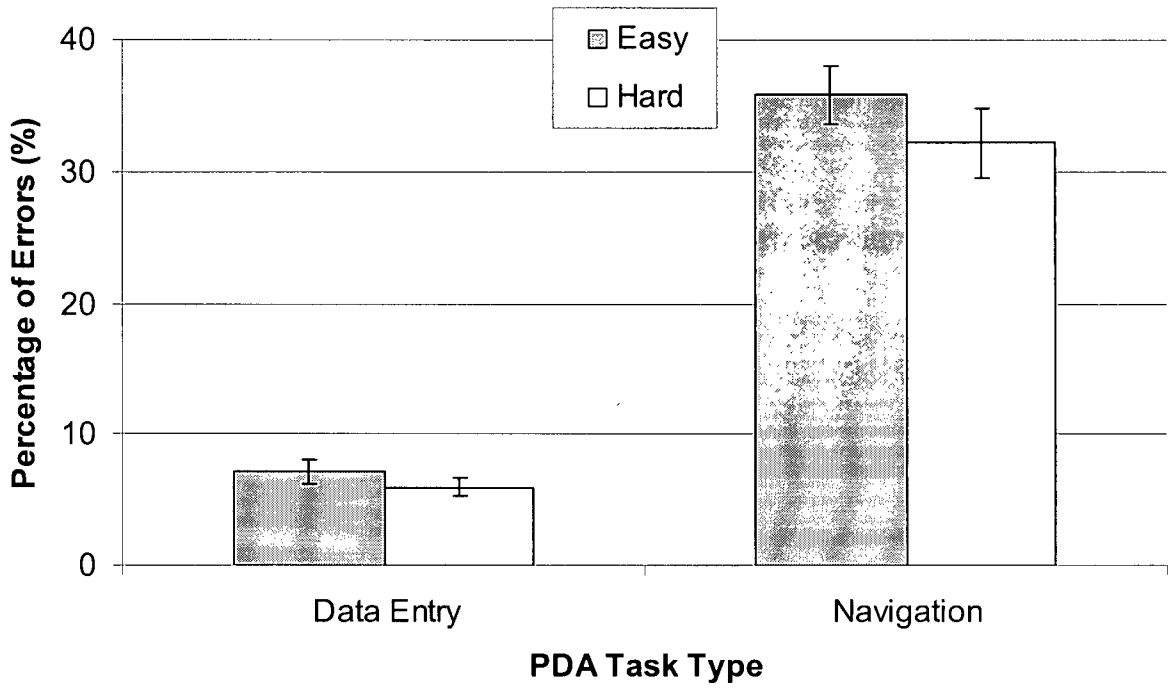


Figure 3. Percentage of errors in data entry and navigation tasks as a function of tone discrimination difficulty.

† vertical bars represents standard errors

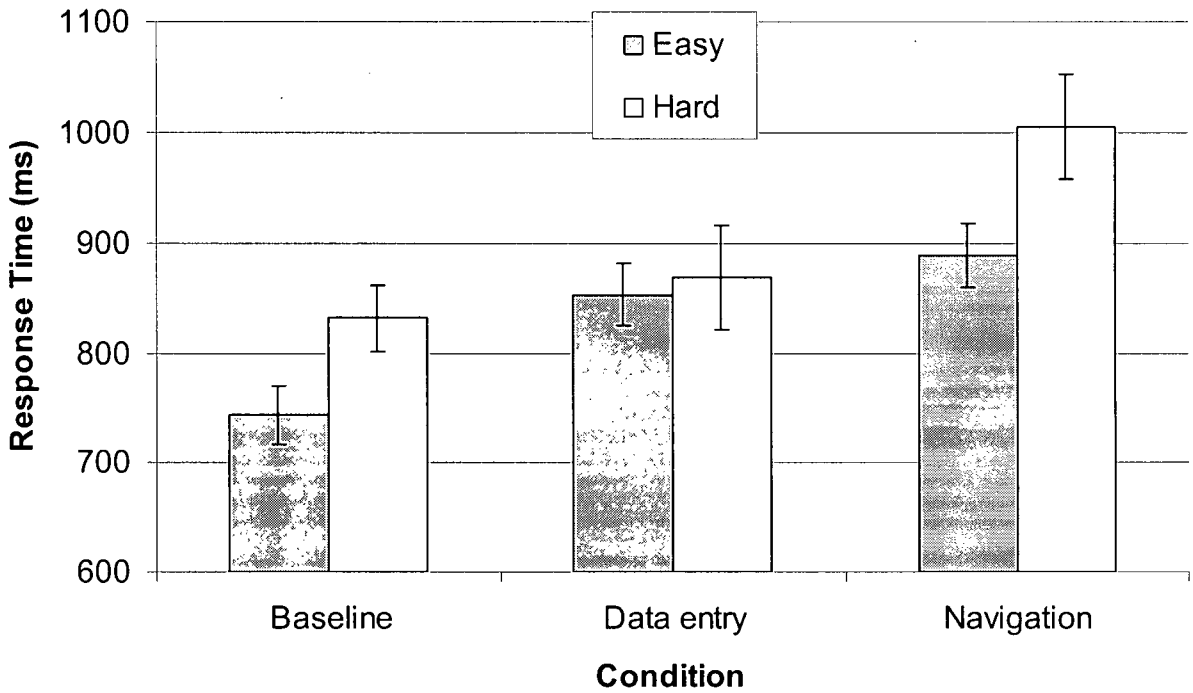


Figure 4. Response time (mean of medians) of correct identifications in the tone discrimination task as a function of tone discrimination difficulty and task conditions.

† vertical bars represents standard errors

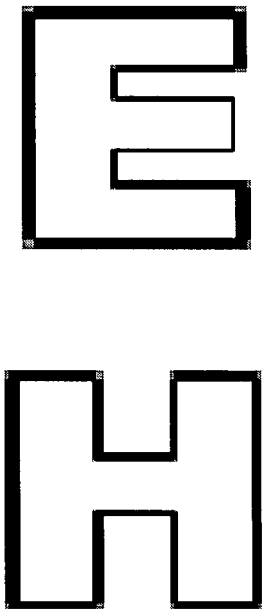

Figure 5. Stimuli for the practice trials of the letter tracing task.

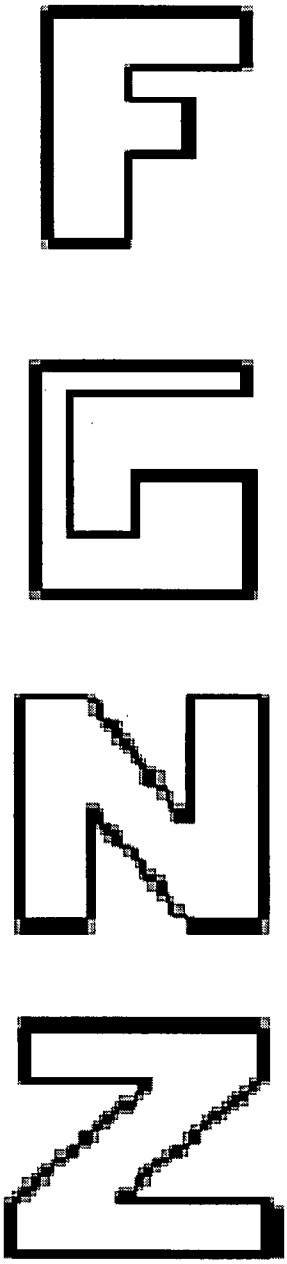

Figure 6. Stimuli for the test trials of the letter tracing task.

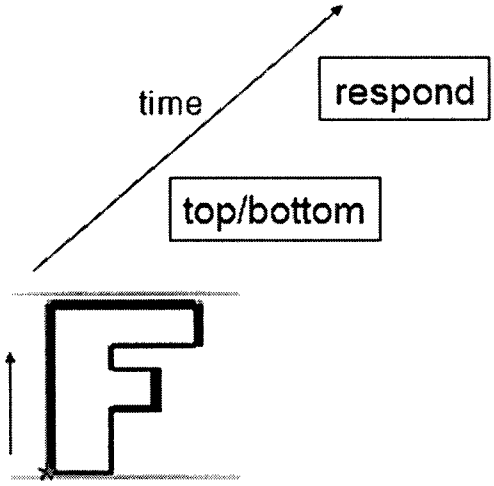


Figure 7. Illustration of a trial of the letter tracing task with top/bottom instructions.

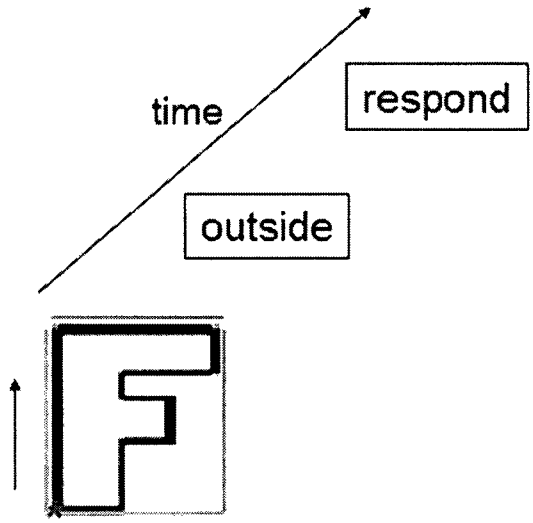


Figure 8. Illustration of a trial of the letter tracing task with outside instructions.

Y N

Y N

Y N

Y N

Y N

Y N

Y N

Y N

Y N

Y N

Y N

Figure 9. Image of staggered Y and N of the output task (pointing).

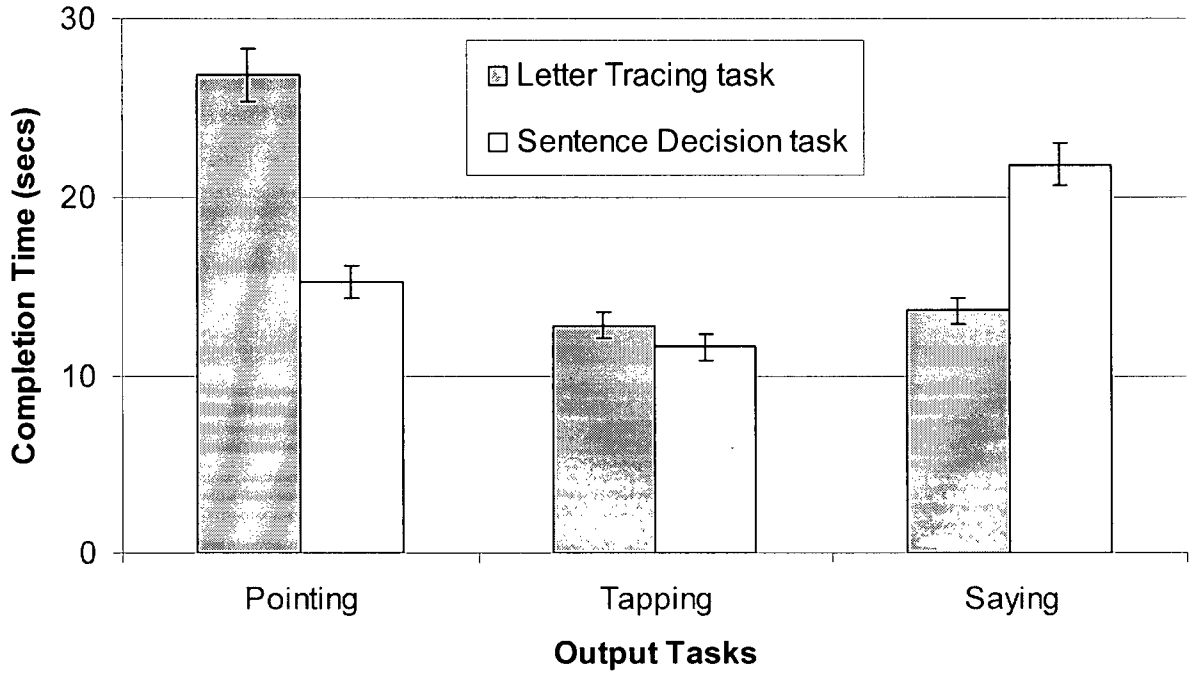


Figure 10. Mean completion time as a function of input task and output task.

† vertical bars represent standard error.

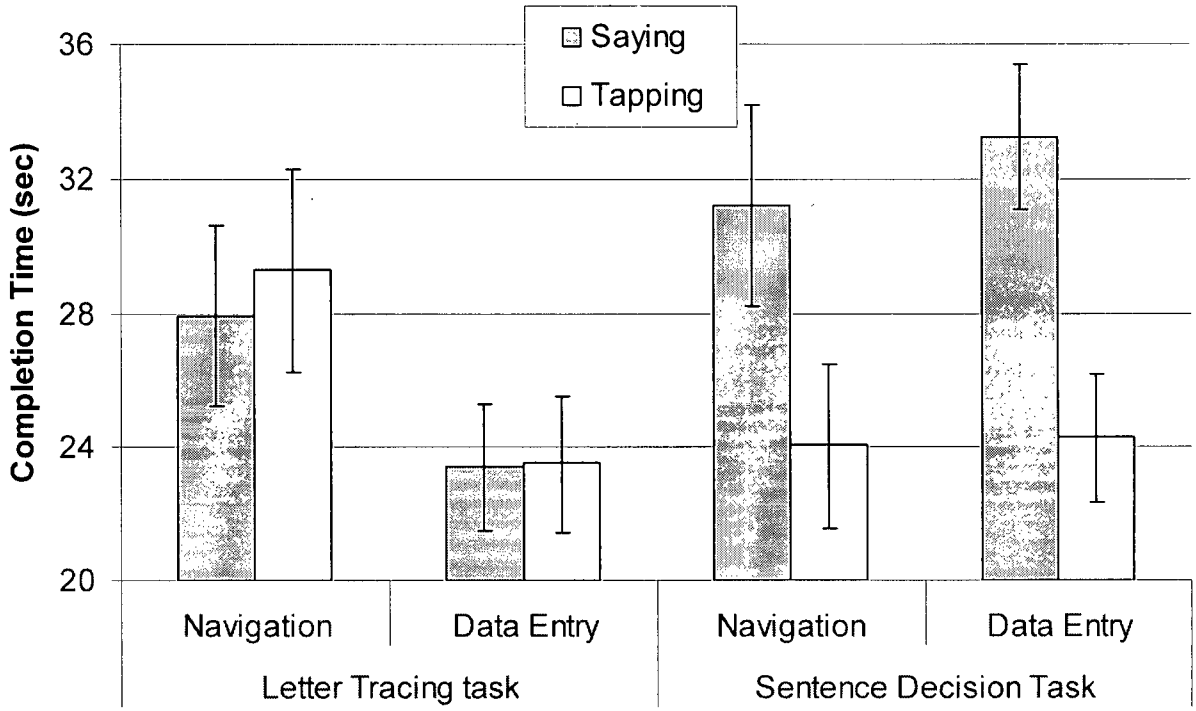


Figure 11. Percentage of PDA task errors as a function of input task, output task, and PDA task type.

† vertical bars represent standard error.

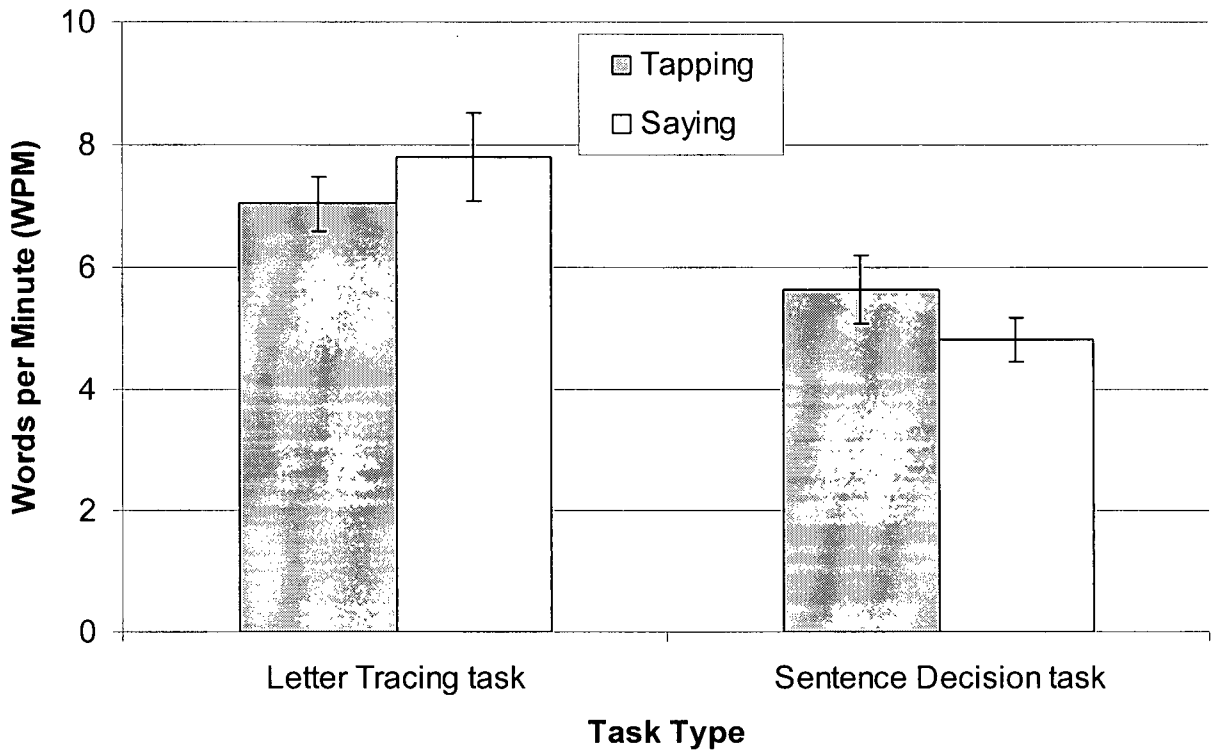


Figure 12. Typing speed (words per minute) in data entry tasks as a function of input task, and output task.

† vertical bars represent standard error.

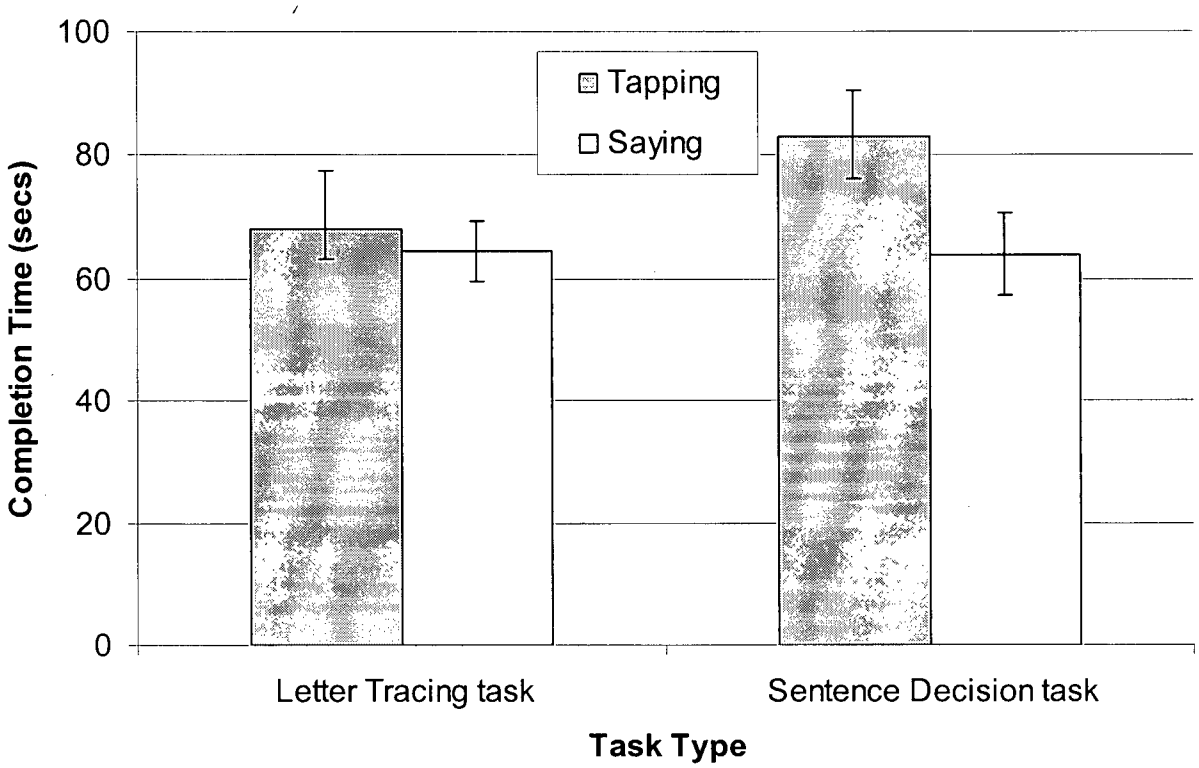


Figure 13. Completion time in navigation tasks as a function of input task, and output task.

† vertical bars represent standard error.

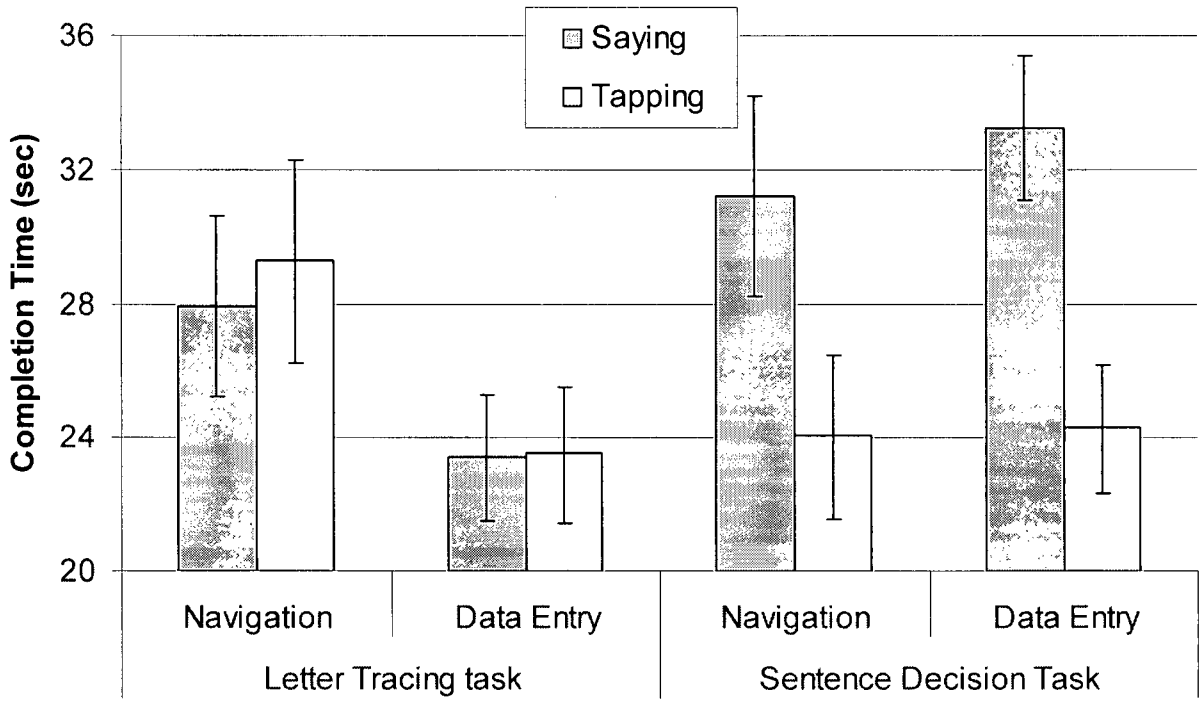


Figure 14. Completion time of the concurrent tasks as a function of input task, output task, and PDA task type.

† vertical bars represent standard error.

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